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Technical Note N-915

CORROSION OF MATERIALS IN HYDROSPACE

PART II - NICKEL AND NICKEL ALLOYS

BY

Fred M. Reinhart

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INTERNAL WORKING PAPER

U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

CORROSION OF MATERIALS IN HYDROSPACE. PART II - NICKEL AND NICKEL ALLOYS

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ABSTRACT

A total of 635 specimens of 75 different nickel alloys were exposed at two different depths in the Pacific Ocean for periods of time varying from 123 to 1064 days to determine the effects of deep ocean environments on their corrosion resistance.

Corrosion rates, types of corrosion, pit depths, effects of welding, stress corrosion cracking resistance, changes in mechanical properties and analyses of corrosion products of the alloys are presented.

Of those alloys tested, the following were practically immune to corrosion: nickel-chromium-iron alloy 718; nickel-iron-chromium alloys, except 902; nickel-chromium-molybdenum alloys; nickel-cobalt-chromium alloy; nickel-chromium-iron-molybdenum alloys; nickel-chromium-cobalt alloy; and nickel-molybdenum-chromium alloy. Alloys attacked by uniform or general corrosion were the cast nickel-copper alloys, nickel-molybdenum-iron alloy; and nickel-molybdenum alloy. Alloys attacked by crevice or pitting corrosion were the nickels; wrought nickel-copper alloys; nickel-chromium-iron alloys except 718; nickel-iron-chromium alloy 902; nickel-tin-zinc alloy; nickel-beryllium alloy; nickel-chromium alloys; and nickel-silicon alloy.

Corrosion resistance of welds in the nickel alloys depends upon the selection of the proper welding electrodes. The nickel alloys were not susceptible to stress corrosion cracking. Corrosion products consisted of oxides, hydroxides, chlorides and oxychlorides. Mechanical properties of the alloys were not adversely affected in a significant way.

The bottom sediments were less aggressive than sea water environments and the lower oxygen content sea water was less aggressive than the higher oxygen content sea water.

PREFACE

The U. S. Naval Civil Engineering Laboratory is conducting a research program to determine the effects of deep ocean environments on materials. It is expected that this research will establish the best materials to be used in deep ocean structures.

A Submersible Test Unit (STU) was designed, on which many test specimens can be mounted. The STU can be lowered to the ocean floor and left for long periods of exposure.

Thus far, two deep ocean test sites in the Pacific Ocean have been selected. Six STUs have been exposed and recovered. Test Site I (nominal depth of 6,000 feet) is approximately 81 nautical miles west-southwest of Port Hueneme, California, latitude 33°44'N and longitude 120°45'W. Test Site II (nominal depth of 2,500 feet) is 75 nautical miles west of Port Hueneme, California, latitude 34°06'N and longitude 120°42'W.

This report presents the results of the evaluation of nickel and nickel alloys.

INTRODUCTION

The development of deep diving submarines which can stay submerged for long periods of time has focused attention on the deep ocean as an operating environment. This has created a need for information about the behavior of common materials of construction as well as newly developed materials with promising potentials, at depths in the ocean.

To study the problems of construction in the deep ocean, project "Deep Ocean Studies" was established. Fundamental to the design, construction and operation of structures, and their related facilities is information about the deterioration of materials in these deep ocean environments. This report is devoted to the portion of the project concerned with determining the effects of these environments on the corrosion of metals and alloys.

The test sites for the deep ocean exposures are shown in Figure 1 and their specific geographical locations are given in Table 1. The complete oceanographic data at these sites obtained during NCEL cruises from 1961 to 1967 are summarized in Figure 2. Because of the minimum-oxygen concentration zone found between the 2,000-3,000 foot depths during the early oceanographic cruises, it was decided to establish the second exposure site (STU II-1 and II-2) at a nominal depth of 2,500 feet.

A summary of the characteristics of the bottom waters 10 feet above the bottom sediments at the different exposure sites is given in Table 1.

Sources of information pertaining to the biological characteristics of the bottom sediments, biological deterioration of materials, detailed oceanographic data, and construction, emplacement and retrieval of STU structures are given in Reference 1.

The procedures for the preparation of the specimens for exposure and for evaluating them after exposure are described in Reference 2.

Previous reports pertaining to the performance of materials in the deep ocean environments are given in References 1 through 6.

This report is a discussion of the corrosion of nickel and some nickel alloys for the six exposure periods shown in Table 1.

RESULTS AND DISCUSSIONS

The results presented and discussed herein also include the corrosion data for the nickels and nickel alloys exposed on the STU structures for the International Nickel Company, Incorporated. Permission for their incorporation in this report has been granted by the International Nickel Company, Incorporated, Reference 7. Results from other participants in the NCEL study are also included, U. S. Navy Marine Engineering Laboratory (Reference 8) and Chemistry Division, NCEL (Reference 9). Deep ocean data from the Atlantic Ocean (References 10 and 11), surface data from the Atlantic Ocean (Reference 12) and surface data from the Pacific Ocean (References 13 and 14) are included for comparison purposes.

NICKEL

The chemical compositions of the nickels are given in Table 2, their corrosion rates and types of corrosion in Table 3, and changes in mechanical properties in Table 4.

Nickel is passive (resistant) in moving sea water but is subject to local attack or pitting in stagnant sea water. Fouling organisms, deposits, and crevices cause pitting and crevice (oxygen concentration cell) corrosion.

The corrosion rates and types of corrosion of seven nickels (94 percent minimum nickel) are given in Table 3. Crevice corrosion and edge corrosion (on the ends) were the two types which were responsible for practically all the corrosion damage. Corrosion rates calculated from weight losses are most meaningful and valuable when the type of corrosion is either uniform or general; therefore, corrosion rates for nickels would not be the best criteria for assessing corrosion. To obtain a complete evaluation of the corrosion of an alloy, corrosion rates, maximum and average pit depths, pitting frequency or pitting factor, type of corrosion, changes in mechanical properties, and resistance to stress corrosion cracking should be determined.

In the case of the nickels, there was very little surface corrosion so little emphasis can be placed on corrosion rates. The two types of corrosion encountered (crevice and edge penetration) can be extremely damaging from the standpoint of reliability. The edge penetration was caused by the microcracks formed during the shearing operation which illustrates dramatically the corrosion damage which can be caused by this fabricating procedure. Penetration of as much as an inch during six months of exposure was found. For sea water applications, shearing or punching of holes should not be permitted; only sawing, machining or drilling.

The Naval Applied Science Laboratory[11] reported that nickel 200 was practically unattacked after 199 days of exposure at a depth of 4,500 feet in the Tongue-of-the-Ocean (TOTO), Atlantic Ocean. This is in contrast to the results obtained in the Pacific Ocean where the corrosion rates in the water were low at both depths; from less than 0.1 to 0.7 MPY at 5,640 feet for 123 days and 0.5 MPY at 2,340 feet for 197 days, but there was crevice corrosion on nickel at both depths.

Although the Naval Research Laboratory[14] reported concentration cell and pitting (average depth, 125 to 143 mils) corrosion of nickel 200 in surface sea water at Fort Amador, Panama Canal Zone, Pacific Ocean, the corrosion rate of nickel decreased with time of exposure as shown in Figure 3. However, as also shown in Figure 3, the corrosion rates of nickel 200 at a nominal depth of 6,000 feet in the Pacific Ocean increased sharply with time of exposure to 2 years and then decreased. After 2 years of exposure they are comparable with those for surface sea waters at Fort Amador. As previously emphasized, more weight must be given to concentration cell, crevice and pitting types of corrosion as a basis for recommending nickels for sea water applications than to corrosion rates calculated from weight loss determinations.

There was no definite correlation between corrosion rates of most of the nickels at the nominal 6,000 foot depth and at the nominal 2,500 foot depth. Only cast nickel-210 and nickel-301 corroded at consistently slower rates at the 2,500 foot depth than at the 6,000 foot depth both in the sea water and in the bottom sediments. At both depths these two nickels corroded at slower rates in the bottom sediment than in the sea water.

The nickel containing 4.5 percent aluminum (nickel 301) was more susceptible to crevice corrosion than the other nickels. Cast nickel (nickel 210) was less susceptible to crevice corrosion than the other nickels but was attacked more by the pitting type of corrosion.

The weld beads were preferentially corroded after 402 days of exposure at a depth of 2,370 feet in the sea water when nickel was welded by the inert gas welding technique using filler metal 61 and by the metal-arc welding technique using welding electrode 141. The preferential corrosion of filler metal 61 is shown in Figure 4. However, in the bottom sediment the weld bead made with filler metal 61 was not preferentially corroded.

Metallographic examinations of the weld materials and the adjacent-heat-affected-zones showed no evidence of selective corrosion at grain boundaries. It is, therefore, concluded that the weld bead alloy was anodic to the parent nickel in the sea water but not in the bottom sediment.

Nickel 200 was not susceptible to stress corrosion cracking when exposed at a depth of 2,370 feet for 402 days at tensile stresses equivalent to 50 and 75 percent of its yield strength (12,500 and 18,700 psi, respectively).

Exposures for periods of time as long as 1064 days at a depth of 5,300 feet were not detrimental to the mechanical properties of nickel 200, Table 4.

NICKEL-COPPER ALLOYS

The chemical compositions of the nickel-cooper alloys are given in Table 5, their corrosion rates and types of corrosion in Table 6 and changes in mechanical properties in Table 7.

The nickel-copper alloys have excellent corrosion resistance in sea water except that in slowly moving or stagnant sea water they are subject to pitting. This is particularly true if fouling organisms are present and attach themselves to the metal. They are inherently passive, hence in environments deficient in oxygen this passivity is destroyed locally and they pit at these local anodes or corrode by oxygen concentration cell type of corrosion in crevices.

The corrosion rates of nickel-copper 400 alloy at depth and at the surface in both the Atlantic and Pacific Oceans are shown in Figure 5. Even though there was both pitting and fouling of specimens in all surface exposures, the corrosion rates decreased with increase in duration of exposure. However, due to the higher average temperature at the Panama Canal Zone, the corrosion rates there were three times as great as those at Port Hueneme, California and at Harbor Island, North Carolina.

The corrosion rates at nominal depths of 2,500 and 6,000 feet in the Pacific varied with duration of exposure so that it was not possible to construct smooth curves. This vacillation of the corrosion rates is attributed to the pitting and crevice types of corrosion. The pitting of nickel-copper alloy 400 after 1064 days of exposure partially embedded in the bottom sediment at a depth of 5,300 feet is shown in Figure 6. The unpitted portion on the right was embedded in the bottom sediment; the pitted portion extended above the sediments. For this reason the corrosion rates at both depths in sea water are shown as a band in Figure 5 which encompasses all but three of the 17 values. For duration of exposure longer than 400 days this band is between the two curves for surface corrosion rates. The low oxygen concentration environment (2,500 foot depth) was of the same aggressiveness as the higher oxygen environment (6,000 foot depth).

There was neither pitting nor crevice corrosion of this alloy at a depth of 5,600 feet in the Atlantic Ocean. In fact, there was no visible corrosion after 1050 days of exposure, Figure 5. This excellent resistance to corrosion at a depth of 5,600 feet in the Atlantic Ocean indicates that the environment at this location is different from the environment at a depth of 5,500 feet in the Pacific Ocean. The oxygen concentration in the Atlantic has been reported as 5.7 milliliters per liter (at least as high as at the surface) and no fouling organisms were reported, but, in addition the current must have been high enough to prevent stagnation: all three conditions are usually necessary to prevent pitting.

There was a similar variability in corrosion rates of the nickel-copper 400 alloy partially embedded in the bottom sediments which is also attributed to the crevice and pitting types of corrosion. At the 5,500 foot depths the depths of the pits and the severity of the crevice corrosion increased with increasing duration of exposure.

When nickel-copper 400 alloy was welded with filler metal 60 by the inert gas welding process the weld bead both in the sea water and in the bottom sediment after 402 days of exposure at a depth of 2,370 feet was selectively attacked as shown in Figure 7. When welded with electrodes 130 and 180 by the metal-arc welding process the weld beads were not selectively corroded, the corrosion was uniform and no more severe than that on the unwelded sheet.

Nickel-copper alloy 400 was not susceptible to stress corrosion cracking when exposed at stresses equivalent to 50 and 75 percent of its yield strength for 402 days at a depth of 2,370 feet.

The mechanical properties of the unwelded nickel-copper 400 alloy were not impaired by exposure at nominal depths of 2,500 and 6,000 feet for periods of time of 402 and 1064 days, respectively except after 751 days at 5,500 feet, Table 7. The 22 percent decrease in the elongation after 751 days of exposure at a depth of 5,500 feet was due to the deep pits.

The percent elongation of the welded specimens decreased with attendant increases in the yield strengths as shown in Table 7. This is not considered significant except for the specimen in the sea water welded with filler metal 60 which broke in a weld defect.

Nickel-copper alloys 402, 406, and K-500 behaved much the same as the 400 alloy in that their corrosion rates vacillated between less than 0.1 and 1.5 MPY due to the severity of crevice and pitting corrosion. After 1096 days of exposure at the surface in the Atlantic Ocean, Harbor Island, North Carolina, the corrosion rate of nickel-copper alloy K-500 was 0.8 MPY which compares favorably with its behavior at depth in the Pacific Ocean.[7] Most of the corrosion at the surface was also due to localized corrosion.

Cast nickel-copper alloys 410 and K-505 corroded uniformly as shown in Table 6. The corrosion rates of the cast-410, in general, decreased with an increase in the time of exposure at both depths, 2,350 and 5,500 feet as shown in Figure 8, and in both cases the corrosion rates in the bottom sediments were less than those in the sea water at the same depth. After 1064 days of exposure at a depth of 5,300 feet the corrosion rates in the sea water and in the bottom sediment were about the same. The corrosion rates at a depth of 2,350 feet were less than those at a depth of 5,500 feet. Initially the cast nickel-copper K-505 alloy corroded at a greater rate in the bottom sediment than in the sea water but after 1064 days of exposure at a depth of 5,500 feet, it was lower than in sea water as shown in Figure 9. The general trend was for the corrosion rates to decrease as the duration of exposure increased. The corrosion rates at 2,350 feet were lower than those at 5,500 feet.

Nickel-copper 60 alloy was attacked by the crevice type of corrosion at both depths, Table 6. In most cases the crevice corrosion was greater on the specimens exposed in the sea water than on those partially embedded in the bottom sediments.

X-ray diffraction, spectrochemical and chemical analyses of corrosion products removed from nickel-copper alloys 400 and K-500 showed that they were composed of cupric oxide (CuO), nickel oxide (NiO), nickel hydroxide ($Ni(OH)_2$), cupric chloride ($CuCl_2$), copper-oxy-chloride ($CuCl_2.3CuO.4H_2O$), a trace of nickel sulfide (NiS) and phosphate, chloride and sulfate ions.

NICKEL ALLOYS

The chemical compositions of the nickel alloys are given in Table 8, their corrosion rates and types of corrosion in Table 9, their stress corrosion resistance in Table 10 and changes in mechanical properties in Table 11.

There were no significant weight losses or any visible corrosion on any of the following alloys:

a. Ni-Cr-Fe 718, unwelded and welded

b. Ni-Cr-Mo #3

c. Ni-Cr-Mo 625

d. Ni-Co-Cr 700 except for 3 specimens with incipient crevice corrosion

e. Ni-Cr-Fe-Mo F

f. Ni-Cr-Fe-Mo G

g. Ni-Cr-Fe-Mo X except for 1 specimen with incipient crevice corrosion

h. Ni-Cr-Co 41

i. Ni-Mo-Cr C

The U. S. Navy Marine Engineering Laboratory also reported no visible corrosion on nickel-molybdenum-chromium alloy C at depth in the Pacific Ocean.[8]

Nickel-Chromium-Iron Alloys

Alloys 600, cast 610, X750 and 88 were attacked chiefly by the crevice type of corrosion with some pitting in a few specimens (see Table 9) both in the sea water and when partially embedded in the bottom sediments. Generally, the crevice corrosion was less severe on the specimens partially embedded in the bottom sediments than on the specimens totally exposed in the sea water.

When alloy 600 was welded with electrodes 132, 62 and 82 the weld bead materials were selectively attacked and were perforated after 402 days of exposure in the sea water at a depth of 2,370 feet. In addition, there was line corrosion along the edges of the weld beads made from electrodes 62 and 82. Also, there was severe tunneling corrosion to perforation in the heat-affected zone of alloy 600 adjacent to the weld bead made with electrode 82 as shown in Figure 10. The line corrosion and selective attack of the weld beads indicates that the weld bead materials were anodic to the parent sheet material (alloy 600). However, when alloy 600 was welded with electrode 182 the only observable corrosion after 402 days of exposure in the sea water at a depth of 2,370 feet was a slight roughening of weld bead indicating that weld beads made with this composition electrode are compatible (the same corrosion potential in sea water) with the parent metal and is the preferred welding electrode.

After 402 days of exposure in the sea water at a depth of 2,370 feet, there was tunnel corrosion in the heat-affected zone and along the edge of the weld bead in alloy X750 which had been welded with electrode 718 by the tungsten electrode inert gas welding process. When alloy X750 was welded with electrode 69 by the tungsten electrode inert gas welding process there was no selective attack of the weld bead material or in the heat affected zone.

There was no visible corrosion on alloy 718 unwelded and when welded with electrode 718 by the tungsten electrode inert gas welding process after 402 days of exposure in the sea water at a depth of 2,370 feet.

Nickel-Iron-Chromium Alloys

There was either no visible corrosion or there was crevice corrosion varying from incipient to 35 mils deep on alloys 800, 804, 825, 825 sensitized (heated for 1 hour at 1200°F), 825 Cb, 901 and 902, Table 9. There was crevice corrosion 6 mils deep on alloy 800 after 1064 days of exposure in the bottom sediment at a depth of 5,300 feet; only incipient crevice corrosion on alloys 804, 825 Cb and 901 at both depths, crevice corrosion 22 mils deep on alloy 825 after 751 days of exposure in the sea water at a depth of 5,640 feet; crevice corrosion 4 mils deep on alloy 825 (sensitized) after 1064 days of exposure in the bottom sediment at a depth of 5,300 feet; and crevice corrosion 35 mils deep on alloy 902, after 402 days of exposure in the sea water at a depth of 2,370 feet.

The U. S. Navy Marine Engineering Laboratory found essentially the same corrosion behavior of alloy 825 which was exposed on STUs I-3 and I-2 for 123 and 751 days at a depth of 5,640 feet, Reference 8. Crevice corrosion was 63 mils deep (perforated) after 751 days with scattered pitting to 1 mil deep. There was crevice corrosion to 57 mils deep and scattered pitting to a depth of 2 mils after 386 days of exposure of companion specimens at the surface at Harbor Island, North Carolina. These data indicate that the corrosion of alloy 825 is slightly faster at the surface in the Atlantic than at depth in the Pacific.

The corrosion behavior of these alloys was the same both in sea water and in the bottom sediments.

After 402 days of exposure in sea water at a depth of 2,370 feet, there was end penetration of the weld bead material when alloy 800 was welded with electrode 82 and line corrosion along the weld bead when alloy 800 was welded with electrode 138. The line corrosion along the weld bead is indicative of the presence of a line of anodic material along the weld bead.

Nickel-Molybdenum-Iron Alloy B

Alloy B was corroded uniformly except for a groove about 4 mils deep at the mud line after 403 days at a depth of 6,780 feet and for incipient crevice and pitting corrosion in the bottom sediment after 197 days at a depth of 2,340 feet.

The corrosion rates of alloy B are shown in Figure 11. At the 5,500 foot depth in the sea water the corrosion rate increased sharply between 123 and 403 days of exposure and decreased gradually thereafter with increasing duration of exposure. In the bottom sediment at a depth of 5,500 feet, there was generally a decrease in the corrosion rate with increasing duration of exposure and the corrosion rate was lower than in the sea water. The corrosion rates at the 2,350 foot depth increased between 200 and 400 days of exposure the increase being greater in the sea water than in the bottom sediment.

Nickel-Tin-Zinc Alloy 23

Alloy 23 was susceptible to severe crevice corrosion (56 mils in 751 days) and to pitting corrosion (35 mils in 1064 days).

Nickel-Beryllium Alloy

The nickel-beryllium alloy specimens were in the form of bars 0.94 inch diameter which were pitted on the ends to depths of 17 mils in the sea water and 8 mils in the bottom sediment. The corrosion rate in the sea water was greater than that in the bottom sediment.

Nickel-Chromium Alloys

Alloys 65-35, 75 and 80-20 were attacked by crevice corrosion which varied in severity from incipient to perforation (50 mils) both in the sea water and in the bottom sediment. The corrosion rates usually were less than 0.1 mils penetration per year; in one case, after 751 days of exposure at a depth of 5,640 feet in sea water the rate was 0.5 mils penetration per year. Because of the localized nature of the corrosion, low corrosion rates are misleading if considered by themselves.

Nickel-Molybdenum Alloy 2

Alloy 2 was attacked by general corrosion; therefore, corrosion rates calculated from weight losses are meaningful and significant. The corrosion rates of alloy 2 are shown in Figure 12. At both depths, 5,500 and 2,350 feet, the corrosion rates increased with increasing duration of exposure. No explanation is offered at this time for the exceptionally high corrosion rate in sea water after 751 days of exposure at a depth of 5,640 feet. The corrosion rates were less in the bottom sediments than in the sea water at both depths.

Nickel-Silicon Alloy D

Alloy D was attacked by the crevice and pitting types of corrosion. The most severe attack was after 1064 days of exposure in the sea water at a depth of 5,300 feet; crevice corrosion extended to a depth of 42 mils and pitting corrosion to a depth of 38 mils.

STRESS CORROSION

Nickel-iron-chromium alloy 825 and nickel-molybdenum-chromium alloy C were exposed in the stressed condition at stresses equivalent to 35, 50 and 75 percent of their yield strengths, as shown in Table 10. Alloy 825 was not susceptible to stress corrosion cracking after 402 days of exposure at a depth of 2,370 feet. Alloy C was not susceptible to stress corrosion cracking for periods of exposure as long as 751 days at a depth of 5,640 feet.

MECHANICAL PROPERTIES

The changes in the mechanical properties of the nickel alloys are given in Table 11. The mechanical properties of nickel-iron-chromium alloy 825 and nickel-molybdenum-chromium alloy C were not impaired by exposure to sea water or in the bottom sediments for periods of time of 751 and 1064 days at the nominal depth of 5,500 feet. There was considerable decrease (49 percent) in the percent elongation of nickel-iron-chromium alloy 902 after 402 days of exposure at a depth of 2,370 feet. Since there was no visible corrosion, especially pitting, on the surfaces of the specimens, this decrease cannot justifiably be attributed to corrosion. No reason can be given for this at this time.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to determine the effects of deep ocean environments on the corrosion of nickel and nickel alloys. To accomplish this a total of 635 specimens of 75 different alloys were exposed at nominal depths of 2,350 and 5,500 feet for periods of time varying from 123 to 1064 days.

There was no significant weight loss or any visible corrosion on the following alloys: nickel-chromium-iron alloy 718, nickel-chromium-molybdenum alloys 3 and 625, nickel-cobalt-chromium alloy 700, nickel-chromium-iron-molybdenum alloys F, G and X, nickel-chromium-cobalt alloy 41 and nickel-molybdenum-chromium alloy C.

Four alloys, cast nickel-copper alloys 410 and K-505, nickel-molybdenum-iron alloy B and nickel-molybdenum alloy 2 were attacked by uniform or general corrosion. Their corrosion rates were lower in the bottom sediments than in sea water at both depths, 2,350 and 5,500 feet. The corrosion rates of cast nickel-copper alloys 410 and K-505 at both depths and of nickel-molybdenum-iron alloy B at the 5,500 foot depth, decreased with increasing duration of exposure. The corrosion rates of nickel-molybdenum alloy 2 at both depths and of nickel-molybdenum-iron alloy B at the 2,370 foot depth increased with increasing duration of exposure.

Some alloys were uncorroded except for isolated instances of crevice corrosion. They were nickel-iron-chromium alloys 800, 804, 825, sensitized 825, 825 Cb and 901.

The remaining alloys were attacked either by crevice or pitting corrosion or by both types of corrosion. These alloys were: electrolytic nickel, nickel 200, 201, 211, 270, cast 210 and 301; nickel-copper alloys 400, 402, 406, K-500 and 60; nickel-chromium-iron alloys 600, cast 610, X750 and 88; nickel-iron-chromium alloy 902; nickel-tin-zinc alloy 23, nickel-beryllium; nickel-chromium alloys 65-35, 75 and 80-20; and nickel-silicon alloy D.

There was attack of the weld beads, at the edge of the weld bead or in the heat-affected zone of the following: nickel 200 welded with electrodes 61 and 141; nickel-copper alloy 400 welded with electrode 60; nickel-chromium-iron alloy 600 welded with electrodes 62, 82 and 132; nickel-chromium-iron alloy X750 welded with electrode 718; nickel-iron-chromium alloy 800 welded with electrodes 82 and 138; and nickel-iron-chromium alloy 825 welded with electrode 135.

There was no selective attack when nickel-copper alloy 400 was welded with electrodes 130 and 180; when nickel-chromium-iron alloy 600 was welded with electrode 182; when nickel-chromium-iron alloy X750 was welded with electrode 69; when nickel-iron-chromium alloy 825 was welded with electrode 65; and when nickel-chromium-iron alloy 718 was welded with electrode 718.

Nickel 200, nickel-copper 400, nickel-molybdenum-chromium alloy C and nickel-iron-chromium alloy 825 were immune to stress corrosion cracking.

Corrosion products from the nickel-copper alloys contained cupric oxide (CuO), nickel oxide (NiO), nickel hydroxide ($Ni(OH)_2$), cupric chloride ($CuCl_2$), trace nickel sulfide (NiS), copper oxychloride ($CuCl_2 . 3CuO . 4H_2O$) and phosphate, chloride and sulfate ions.

The mechanical properties of nickel and the nickel alloys were unaffected by exposure at depths in the Pacific Ocean except for decrease in percent elongation of nickel-iron-chromium alloy 902.

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Table 1. STU Locations and Bottom Water Characteristics

Site No.	Lat. N	Long. W	Depth ft	Exposure, Days	Temp. °C	Oxygen, ml/1	Salinity, ppt	pH	Current, Knots, Ave.
Surface	-----	------	65	----	11-17	5.4-6.5	33.76	7.9-8.3	Variable
I-1	33°46'	120°37'	5300	1064	2.6	1.2	34.51	7.5	0.03
I-2	33°44'	120°45'	5640	751	2.3	1.3	34.51	7.6	0.03
I-3	33°44'	120°45'	5640	123	2.3	1.3	34.51	7.6	0.03
I-4	33°46'	120°46'	6780	403	2.2	1.6	34.40	7.7	0.03
II-1	34°06'	120°42'	2340	197	5.0	0.4	34.36	7.5	0.06
II-2	34°06'	120°42'	2370	402	5.0	0.4	34.36	7.5	0.06

Table 2. Chemical Composition of Nickels, Percent by Weight

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Ti	Other	Source 1/
Electrolytic Ni	99.97+Co	----	----	----	-----	----	----	----	-----	INCO 7/
Ni-200 No. 1	99.5	0.05	0.29	0.04	0.006	0.07	0.02	----	-----	NCEL
Ni-200 No. 2	99.5	0.06	0.25	0.15	0.005	0.05	0.05	----	-----	NCEL
Ni-200	99.5	0.06	----	----	-----	----	----	----	-----	INCO 7/
Ni-201	99.5	0.01	----	----	-----	----	----	----	-----	INCO 7/
Ni-211	95.0	----	5.0	----	-----	----	----	----	-----	INCO 7/
Ni-270	99.97	----	----	----	-----	----	----	----	-----	INCO 7/
Cast Ni-210	95.6	----	1.0	----	-----	2.0	----	----	-----	INCO 7/
Ni-301	94.0	----	----	----	-----	----	----	----	4.5Al	INCO 7/
Filler Metal 61	96.0	0.06	0.30	0.10	0.005	0.40	0.02	3.0	-----	NCEL
Electrode 141	96.0	0.05	0.25	0.30	0.005	0.60	0.05	2.2	0.25Al	NCEL

1/ Numbers refer to references at end of paper.

Table 3. Corrosion Rates and Types of Corrosion of Nickels

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of Corrosion[4]	Source[3]
Electrolytic Ni	W	123	5,640	< 0.1	3	C	INCO[7]
Electrolytic Ni	S	123	5,640	0.3	4	C	INCO[7]
Electrolytic Ni	W	403	6,780	1.2	20	C	INCO[7]
Electrolytic Ni	S	403	6,780	0.1	19	C	INCO[7]
Electrolytic Ni	W	751	5,640	0.5	50(PR)	C	INCO[7]
Electrolytic Ni	S	751	5,640	0.1	25	C	INCO[7]
Electrolytic Ni	W	1,064	5,300	0.7	------	PR,50[5]	INCO[7]
Electrolytic Ni	S	1,064	5,300	0.4	50(PR)	C, P to PR,50	INCO[7]
Electrolytic Ni	W	197	2,340	0.4	50(PR)	C, P	INCO[7]
Electrolytic Ni	S	197	2,340	0.1	------	ET, Nu	INCO[7]
Electrolytic Ni	W	402	2,370	0.6	50(PR)	C	INCO[7]
Electrolytic Ni	S	402	2,370	0.2	------	C, I P	INCO[7]
Ni-200, No. 1	W	123	5,640	0.7	Slight	EX E[6]	NCEL
Ni-200	W	123	5,640	< 0.1	2	C	INCO[7]
Ni-200, No. 1	S	123	5,640	1.6	Slight	EX E[6]	NCEL
Ni-200	S	123	5,640	0.3	22	C	INCO[7]
Ni-200, No. 1	W	403	6,780	1.6	79	T to PR,123	NCEL
Ni-200	W	403	6,780	0.6	50(PR)	C	INCO[7]
Ni-200, No. 1	S	403	6,780	1.7	29	T to PR,123	NCEL
Ni-200	S	403	6,780	0.4	------	P,38[7]	INCO[7]
Ni-200, No. 1	W	751	5,640	1.8	116	T	NCEL
Ni-200	W	751	5,640	1.6	50(PR)	C, P to PR	INCO[7]
Ni-200	S	751	5,640	0.1	30	C, P	INCO[7]
Ni-200, No. 1	W	1,064	5,300	1.2	8	EX E[6]	NCEL
Ni-200	W	1,064	5,300	1.1	50(PR)	C, P to PR	INCO[7]
Ni-200, No. 1	S	1,064	5,300	1.0	123(PR)	EX E[6]	NCEL
Ni-200	S	1,064	5,300	0.6	50(PR)	EX E[6]	INCO[7]
Ni-200, No. 1	W	197	2,340	0.5	43	EX E[6]	NCEL
Ni-200	W	197	2,340	0.5	10	SC, P	INCO[7]

Table 3. Corrosion Rates and Types of Corrosion of Nickels (Cont'd.)

Alloy	Envi-1/ ronment	Exposure, Days	Depth, Feet	Corrosion Rate,2/ MPY	Corrosion Crevice, Mils	Type of 4/ Corrosion	Source3/
Ni-200, No. 1	S	197	2,340	0.5	None	EX I 6/	NCEL
Ni-200	S	197	2,340	<0.1	------	ET, Nu	INCO7/
Ni-200, No. 1	W	402	2,370	0.6	3	S ET	NCEL
Ni-200	W	402	2,370	0.6	50(PR)	C	INCO7/
Ni-200, No. 2, welded, electrode 141	W	402	2,370	0.8	------	ET, I P8/	NCEL
Ni-200, No. 2, welded, filler 61	W	402	2,370	0.6	------	ET, I P9/	NCEL
Ni-200, No. 1	S	402	2,370	0.5	------	U10/	NCEL
Ni-200	S	402	2,370	0.2	------	C, I P	INCO7/
Ni-200, No. 2, welded, filler 61	S	402	2,370	0.7	------	U10/	NCEL
Ni-200	W	90	4,500	<0.1	------	NSC	NASL11/
Ni-200	W	180	4,500	<0.1	------	NSC	NASL11/
Ni-200	W	102	4,250	<0.1	------	---	NASL11/
Ni-200	W	199	4,250	<0.1	------	11/	NASL11/
Ni-201	W	123	5,640	0.5	------	P to PR,50	INCO7/
Ni-201	S	123	5,640	1.3	------	P to PR,50	INCO7/
Ni-201	W	403	6,780	0.7	50(PR)	C, P to PR,50	INCO7/
Ni-201	S	403	6,780	0.2	20	C	INCO7/
Ni-201	W	751	5,640	1.1	30(PR)	C, P to PR,30	INCO7/
Ni-201	S	751	5,640	0.2	30(PR)	C, P to PR,30	INCO7/
Ni-201	W	1,064	5,300	0.8	50(PR)	C, P to PR,50	INCO7/
Ni-201	S	1,064	5,300	0.3	50(PR)	C, P to PR,50	INCO7/
Ni-201	W	197	2,340	0.5	50(PR)	C, P12/	INCO7/
Ni-201	S	197	2,340	<0.1	------	I C	INCO7/
Ni-201	W	402	2,370	0.6	50(PR)	C, P to PR,50	INCO7/
Ni-201	S	402	2,370	0.2	------	I C, I P	INCO7/

Table 3. Corrosion Rates and Types of Corrosion of Nickels (Cont'd.)

Alloy	Envi-[1] ronment	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of [4] Corrosion	Source[3]
Ni-211	W	123	5,640	0.3	22	C	INCO[7]
Ni-211	S	123	5,640	0.8	28	C, P	INCO[7]
Ni-211	W	403	6,780	0.8	50(PR)	C, P to PR,50	INCO[7]
Ni-211	S	403	6,780	0.2	29	C	INCO[7]
Ni-211	W	751	5,640	1.3	30(PR)	C	INCO[7]
Ni-211	S	751	5,640	0.3	30(PR)	C	INCO[7]
Ni-211	W	1,064	5,300	1.0	50(PR)	C, P to PR,50	INCO[7]
Ni-211	S	1,064	5,300	0.7	50(PR)	C, P to PR,50	INCO[7]
Ni-211	W	197	2,340	0.5	32(PR)	C	INCO[7]
Ni-211	S	197	2,340	<0.1	------	I C	INCO[7]
Ni-211	W	402	2,370	0.6	50(PR)	C	INCO[7]
Ni-211	S	402	2,370	0.2	------	I C, I P	INCO[7]
Ni-270	W	402	2,370	0.6	50(PR)	C	INCO[7]
Ni-270	S	402	2,370	0.3	------	I C, I P	INCO[7]
Cast Ni-210	W	123	5,640	2.0	------	P, 8m	INCO[7]
Cast Ni-210	S	123	5,640	1.1	------	P, 23m	INCO[7]
Cast Ni-210	W	403	6,780	7.2	70	C	INCO[7]
Cast Ni-210	S	403	6,780	0.3	------	U	INCO[7]
Cast Ni-210	W	751	5,640	3.3	75	C	INCO[7]
Cast Ni-210	S	751	5,640	1.7	67	C, P	INCO[7]
Cast Ni-210	W	1,064	5,300	1.5	------	P, 50	INCO[7]
Cast Ni-210	S	1,064	5,300	0.9	16	C, P, 12	INCO[7]
Cast Ni-210	W	197	2,340	0.6	------	I C, I P	INCO[7]
Cast Ni-210	S	197	2,340	<0.1	------	ET SL	INCO[7]
Cast Ni-210	W	402	2,370	0.7	16	C	INCO[7]
Cast Ni-210	S	402	2,370	0.3	------	G	INCO[7]

Table 3. Corrosion Rates and Types of Corrosion of Nickels (Cont'd.)

Alloy	Envi-1/ ronment	Exposure, Days	Depth, Feet	Corrosion Rate, 2/ MPY	Corrosion Crevice, Mils	Type of 4/ Corrosion	Source 3/
Ni-301	W	123	5,640	2.8	50(PR)	C	INCO 7/
Ni-301	S	123	5,640	3.1	50(PR)	C	INCO 7/
Ni-301	W	403	6,780	4.1	50(PR)	C	INCO 7/
Ni-301	S	403	6,780	1.0	40(PR)	C	INCO 7/
Ni-301	W	751	5,640	3.3	50(PR)	C	INCO 7/
Ni-301	S	751	5,640	2.7	50(PR)	C	INCO 7/
Ni-301	W	1,064	5,300	1.8	50(PR)	C	INCO 7/
Ni-301	S	1,064	5,300	1.1	50(PR)	C, P35m	INCO 7/
Ni-301	W	197	2,340	1.1	50(PR)	C	INCO 7/
Ni-301	S	197	2,340	<0.1	------	I C	INCO 7/
Ni-301	W	402	2,370	0.7	------	SL E	INCO 7/
Ni-301	S	402	2,370	0.2	35(PR)	C	INCO 7/

1/ W = specimens exposed on sides of STU in sea water
S = specimens exposed in base of STU, partially embedded in bottom sediment

2/ MPY = mils penetration per year calculated from weight loss

3/ Numbers refer to references at end of paper

4/ Symbols for type of corrosion

C - crevice
E - edge
ET - etched
EX - extensive
G - general
I - incipient

NSC - no significant corrosion
Nu - non-uniform
Numbers indicate mils: i.e.,
20m - 20 mils maximum
14.6a - 14.6 mils average
20 - 20 mils

P - pitting
PR - perforation
S - severe
SL - slight
T - tunnel
U - uniform
V - very

Table 3. Corrosion Rates and Types of Corrosion of Nickels (Cont'd.)

5/ Numerous pin hole perforations

6/ Ends only, due to shearing

7/ Only one pit

8/ Weld bead severely corroded

9/ Weld bead perforated

10/ Portion in water only; portion in sediment was bright

11/ Covered with hard white scale

12/ Elongated pits

Table 4. Percent Change in Mechanical Properties of Nickel 200 Due to Corrosion

Alloy	Exposure		Original Properties			Percent Change		
	Depth, Feet	Days	Tensile Strength, KSI	Yield Strength, KSI	Elongation Percent	Tensile Strength	Yield Strength	Elongation
Ni-200, No. 1	5,640	123	65.1	17.5	46.0	-0.9	-16.0	- 0.4
	6,780	403				+1.5	+ 1.2	- 1.3
	5,640	751				+1.3	+ 0.5	- 3.7
	5,300	1,064				+0.1	-10.3	-13.3
	2,340	197				0.0	-10.0	- 4.1
	2,370	402				+0.7	+ 3.7	- 5.4

Table 5. Chemical Composition of Nickel-Copper Alloys, Percent by Weight

Alloy	Ni	Cu	C	Mn	Fe	S	Si	Ti	Other	Source[1/]
Ni-Cu 400, No. 1	65.17	32.62	0.11	1.06	0.90	0.007	0.10	---	---	NCEL
Ni-Cu 400, No. 2	66.00	31.50	0.12	0.90	1.35	0.005	0.15	---	---	NCEL
Ni-Cu 400, No. 3	68.02	29.25	0.12	0.99	1.52	0.010	<0.05	---	<0.10Al	NCEL[9/]
Ni-Cu 400, No. 4	65.90	31.75	0.14	0.94	1.07	0.010	0.19	---	<0.10Al	NCEL[9/]
Ni-Cu 400	66.00	32.00	---	0.90	1.40	---	0.20	---	---	INCO[7/]
Filler Metal 60	66.00	30.50	0.03	0.35	0.10	0.005	0.50	2.20	---	NCEL
Electrode 130	68.00	27.00	0.15	2.50	0.50	0.005	0.40	0.30	1.00Al	NCEL
Electrode 180	63.00	28.00	0.03	5.00	0.25	0.005	0.75	0.70	0.30Al 1.50Cb	NCEL
Ni-Cu 402	58.00	40.00	---	0.90	1.20	---	0.10	---	---	INCO[7/]
Ni-Cu 406	84.00	13.00	---	0.90	1.40	---	0.20	---	---	INCO[7/]
Cast Ni-Cu 410	66.00	31.00	---	0.80	1.00	---	1.60	---	---	INCO[7/]
Ni-Cu K-500	65.00	29.50	0.15	0.60	1.00	0.005	0.15	0.50	2.80Al	NCEL
Ni-Cu K-500	65.00	30.00	---	0.60	1.00	---	0.20	---	2.80Al	INCO[7/]
Cast Ni-Cu K-505	64.00	29.00	---	0.80	2.00	---	4.00	---	---	INCO[7/]
Filler Metal 64	65.00	29.50	0.15	0.60	1.00	0.005	0.15	0.50	2.80Al	NCEL
Electrode 134	66.00	27.00	0.25	2.50	1.00	0.005	0.40	0.30	2.00Al	NCEL
Ni-Cu 60	65.00	30.00	---	0.90	2.00	---	1.00	---	1.00Al	INCO[7/]
Ni-Cu	45.00	54.00	---	1.00	0.10	---	---	---	---	INCO[7/]

[1/]Numbers refer to references at end of paper.

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys

Alloy	Envi-1/ ronment	Expo- sure, Days	Depth, Feet	Corrosion Rate,2/ MPY	Corrosion Crevice, Mils	Type of 5/ Corrosion	Source4/
Ni-Cu 400	W	123	5,640	0.8	None	U	NCEL
Ni-Cu 400	W	123	5,640	0.4	None	U	INCO7/
Ni-Cu 400	S	123	5,640	0.5	None	U	NCEL
Ni-Cu 400	S	123	5,640	0.4	5	C, U	INCO7/
Ni-Cu 400	W	403	6,780	0.5	10	P, 20m, 14.6a; E	NCEL
Ni-Cu 400	W	403	6,780	0.8	40(PR)12/	C, U	INCO7/
Ni-Cu 400	S	403	6,780	0.4	10	C; P, 18m, 10a; E	NCEL
Ni-Cu 400	S	403	6,780	0.1	2	C, U	INCO7/
Ni-Cu 400	W	751	5,640	1.0	45	C; P, 45m, 36a; E	NCEL
Ni-Cu 400	W	751	5,640	3.1	40(PR)	C, P	INCO7/
Ni-Cu 400	S	751	5,640	1.3	40(PR)	C	INCO7/
Ni-Cu 400	W	1,064	5,300	0.5	6	G	NCEL
Ni-Cu 400	W	1,064	5,300	0.8	Yes	C, E	NCEL9/
Ni-Cu 400	W	1,064	5,300	1.1	Yes	C, E	NCEL9/
Ni-Cu 400	W	1,064	5,300	0.5	40(PR)	C, P	INCO7/
Ni-Cu 400	S	1,064	5,300	0.6	125(PR)	C; P, 47m, 35a	NCEL
Ni-Cu 400	S	1,064	5,300	0.6	40(PR)	C, CR	INCO7/
Ni-Cu 400	W	123	2,5003/	0.4	None	U	NCEL
Ni-Cu 400	W	197	2,340	0.4	11	C; P, 10m, 9.5a	NCEL
Ni-Cu 400	W	197	2,340	0.4	7	C	INCO7/
Ni-Cu 400	S	197	2,340	0.3	None	U	NCEL
Ni-Cu 400	S	197	2,340	0.2	4	C	INCO7/
Ni-Cu 400	W	402	2,370	0.5	None	P, 14m	NCEL
Ni-Cu 400	W	402	2,370	0.3	None	P, 20m, 17.6a	NCEL
Ni-Cu 400	W	402	2,370	0.8	40(PR)	C,P	INCO7/

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys (Cont'd.)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion		Type of Corrosion[5]	Source[4]
				Rate, MPY[2]	Crevice, Mils		
Ni-Cu 400	S	402	2,370	0.2	None	I P[6]	NCEL
Ni-Cu 400	S	402	2,370	0.3	None	E, I P	NCEL
Ni-Cu 400	S	402	2,370	0.1	None	ET	INCO[7]
Ni-Cu 400, welded, electrode 130	W	402	2,370	0.5	None	I P[7]	NCEL
Ni-Cu 400, welded, electrode 180	W	402	2,370	0.5	None	I P[7]	NCEL
Ni-Cu 400, welded, metal 60	W	402	2,370	0.4	None	I P[8]	NCEL
Ni-Cu 400 welded, metal 60	S	402	2,370	0.4	None	E[9]	NCEL
Ni-Cu 402	W	123	5,640	0.3	None	U	INCO[7]
Ni-Cu 402	S	123	5,640	0.3	None	U	INCO[7]
Ni-Cu 402	W	403	6,780	0.7	None	U	INCO[7]
Ni-Cu 402	S	403	6,780	1.3	Incipient	C	INCO[7]
Ni-Cu 402	W	751	5,640	0.5	14	C, P	INCO[7]
Ni-Cu 402	S	751	5,640	0.3	7	C	INCO[7]
Ni-Cu 402	W	1,064	5,300	0.3	12	C	INCO[7]
Ni-Cu 402	S	1,064	5,300	1.0	50(PR)	C, CR	INCO[7]
Ni-Cu 402	W	197	2,340	0.4	None	U	INCO[7]
Ni-Cu 402	S	197	2,340	<0.1	Incipient	C	INCO[7]
Ni-Cu 402	W	402	2,340	0.7	32(PR)	C, P	INCO[7]
Ni-Cu 402	S	402	2,370	<0.1	Incipient	C	INCO[7]

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys (Cont'd.)

Alloy	Envi-1/ ronment	Expo-sure, Days	Depth, Feet	Corrosion		Type of 5/ Corrosion	Source 4/
				Rate, 2/ MPY	Crevice, Mils		
Ni-Cu 406	W	123	5,640	0.2	8	C	INCO7/
Ni-Cu 406	S	123	5,640	0.4	50(PR)	C	INCO7/
Ni-Cu 406	W	403	6,780	0.5	50(PR)	C	INCO7/
Ni-Cu 406	S	403	6,780	<0.1	Incipient	C	INCO7/
Ni-Cu 406	W	751	5,640	0.7	40(PR)	C	INCO7/
Ni-Cu 406	S	751	5,640	0.3	40(PR)	C	INCO7/
Ni-Cu 406	W	1,064	5,300	0.8	50(PR)	C	INCO7/
Ni-Cu 406	S	1,064	5,300	1.0	50(PR)	C	INCO7/
Ni-Cu 406	W	197	2,340	0.5	23	C	INCO7/
Ni-Cu 406	S	197	2,340	<0.1	None	U ET	INCO7/
Ni-Cu 406	W	402	2,370	0.6	50(PR)	C	INCO7/
Ni-Cu 406	S	402	2,370	0.1	30	C	INCO7/
Cast Ni-Cu 410	W	123	5,640	0.8	None	U	INCO7/
Cast Ni-Cu 410	S	123	5,640	0.5	None	U	INCO7/
Cast Ni-Cu 410	W	403	6,780	1.1	None	U	INCO7/
Cast Ni-Cu 410	S	403	6,780	<0.1	None	EBSL	INCO7/
Cast Ni-Cu 410	W	751	5,640	0.9	None	U	INCO7/
Cast Ni-Cu 410	S	751	5,640	0.5	None	U	INCO7/
Cast Ni-Cu 410	W	1,064	5,300	0.5	None	G	INCO7/
Cast Ni-Cu 410	S	1,064	5,300	0.4	None	G	INCO7/
Cast Ni-Cu 410	W	197	2,340	0.6	None	U	INCO7/
Cast Ni-Cu 410	S	197	2,340	0.2	None	U	INCO7/
Cast Ni-Cu 410	W	402	2,370	0.4	None	G	INCO7/
Cast Ni-Cu 410	S	402	2,370	0.1	None	I P	INCO7/

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys (Cont'd.)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of Corrosion[5]	Source[4]
Ni-Cu K-500	W	123	5,640	0.4	9	C	INCO[7]
Ni-Cu K-500	S	123	5,640	0.7	11	C	INCO[7]
Ni-Cu K-500	W	403	6,780	0.3	18	C	INCO[7]
Ni-Cu K-500	S	403	6,780	<0.1	2	C	INCO[7]
Ni-Cu K-500	W	751	5,640	3.6	30(PR)	C	INCO[7]
Ni-Cu K-500	S	751	5,640	1.5	30(PR)	C	INCO[7]
Ni-Cu K-500	W	1,064	5,300	0.9	30(PR)	C	INCO[7]
Ni-Cu K-500	S	1,064	5,300	0.7	None	CR, PR30	INCO[7]
Ni-Cu K-500	W	197	2,340	0.4	None	U	INCO[7]
Ni-Cu K-500	S	197	2,340	0.2	None	U	INCO[7]
Ni-Cu K-500	W	402	2,370	0.6	None	P, 33m, 27.4a	NCEL
Ni-Cu K-500	W	402	2,370	0.5	46	C; P, 38m, 25a	NCEL
Ni-Cu K-500	W	402	2,370	0.6	30(PR)	C	INCO[7]
Ni-Cu K-500	S	402	2,370	0.3	None	2P, 11 & 12	NCEL
Ni-Cu K-500	S	402	2,370	0.3	37	C; P, 48m, 26a	NCEL
Ni-Cu K-500	S	402	2,370	<0.1	None	ET	INCO[7]
Ni-Cu K-500, welded, electrode 134	W	402	2,370	0.6	None	(10)	NCEL
Ni-Cu K-500, welded, electrode 64	W	402	2,370	0.5	None	(11)	NCEL
Cast Ni-Cu 505	W	123	5,640	1.4	None	U	INCO[7]
Cast Ni-Cu 505	S	123	5,640	2.4	None	U	INCO[7]
Cast Ni-Cu 505	W	403	6,780	1.9	None	U	INCO[7]
Cast Ni-Cu 505	S	403	6,780	<0.1	Incipient	C	INCO[7]

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys (Cont'd.)

Alloy	Envi-1/ ronment	Expo-sure, Days	Depth, Feet	Corrosion		Type of 5/ Corrosion	Source4/
				Rate,2/ MPY	Crevice, Mils		
Cast Ni-Cu 505	W	751	5,640	1.0	None	U	INCO7/
Cast Ni-Cu 505	S	751	5,640	2.1	None	U	INCO7/
Cast Ni-Cu 505	W	1,064	5,300	1.0	None	G	INCO7/
Cast Ni-Cu 505	S	1,064	5,300	0.5	None	G	INCO7/
Cast Ni-Cu 505	W	197	2,340	0.3	None	U	INCO7/
Cast Ni-Cu 505	S	197	2,340	0.2	None	U	INCO7/
Cast Ni-Cu 505	W	402	2,370	0.3	None	G	INCO7/
Cast Ni-Cu 505	S	402	2,370	<0.1	None	ET	INCO7/
Ni-Cu 60	W	123	5,640	3.0	50(PR)	C	INCO7/
Ni-Cu 60	S	123	5,640	2.1	24	C	INCO7/
Ni-Cu 60	W	403	6,730	3.0	50(PR)	C	INCO7/
Ni-Cu 60	S	403	6,780	<0.1	-	I C	INCO7/
Ni-Cu 60	W	751	5,640	4.9	62(PR)	S C	INCO7/
Ni-Cu 60	S	751	5,640	1.3	62(PR)	S C	INCO7/
Ni-Cu 60	W	1,064	5,300	1.4	62(PR)	S C	INCO7/
Ni-Cu 60	S	1,064	5,300	0.9	33	C, CR	INCO7/
Ni-Cu 60	W	197	2,340	0.5	17	C	INCO7/
Ni-Cu 60	S	197	2,340	0.1	-	U	INCO7/

1/ W = specimens exposed on sides of STU in sea water
S = specimens exposed in base of STU partially embedded in bottom sediment

2/ MPY = mils penetration per year calculated from weight loss

3/ Specimens freely suspended 2,500 feet below the surface in 5,640 feet of water

4/ Numbers refer to references at end of paper

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys (Cont'd.)

5/ Symbols for type of corrosion

C - Crevice
Co - Coppering-selective attach where copper appears on surface of specimen similar to dezincification
CR - Cratering
DA - Dealuminification
DZ - Dezincification
E - Edge
EBSL - Etched below sediment line
ET - Etched
EX - Extensive
G - General
GBSL - General below sediment line
I - Incipient
IG - Intergranular
M - Corroded at mud line
MO - Moderate
NC - No visible corrosion
Numbers indicate mils:
i.e.- 20m = 20 mils maximum
14.6a = 14.6 mils average
20 = 20 mils
P - Pitting
PR - Perforation
S - Severe
SCC - Stress corrosion cracking
SL - Slight
T - Tunnel
U - Uniform
V - Very
XF - Exfoliation

Table 6. Corrosion Rates and Types of Corrosion of Nickel-Copper Alloys (Cont'd.)

6/ Incipient pitting in water, portion in bottom sediment shiny

7/ Incipient pitting, weld uniform

8/ Incipient pitting, weld severely pitted

9/ Etched, weld severely pitted

10/ Weld uniform; line corrosion at edge of weld bead; pitting, 14 mils max., 9.9 mils average

11/ Weld uniform; pitting, 21 mils max., 17.6 mils average

Table 7. Percent Change in Mechanical Properties of Nickel-Copper Alloys

Alloy	Exposure		Original Properties			Percent Change		
	Depth, Feet	Days	Tensile Strength, KSI	Yield Strength KSI	Elongation Percent	Tensile Strength	Yield Strength	Elongation
Ni-Cu 400, No. 1	--	--	75.1	28.8	44.3	--	--	--
	5,640	123	--	--	--	+2.1	+1.4	+ 0.5
	6,780	403	--	--	--	+2.1	+2.1	- 2.6
	5,640	751	--	--	--	-2.1	-1.7	-21.7
	5,300	1,064	--	--	--	+2.5	+4.9	- 3.4
	2,340	197	--	--	--	+2.3	+1.2	- 0.7
	2,370	402	--	--	--	+2.7	+5.7	- 1.0
Ni-Cu 400, No. 2	--	--	77.3	29.4	43.6	--	--	--
Unwelded	2,370	402	--	--	--	0	0	0
Welded, F.M. 60, W	2,370	402	--	--	--	-2.5	+17.4	-34.0*
Welded, F.M. 60, S	2,370	402	--	--	--	+0.9	+14.0	-25.5
Welded E 130	2,370	402	--	--	--	0	+14.3	-14.6
Welded E 180	2,370	402	--	--	--	0	+16.3	-24.8
Ni-Cu K-500	--	--	97.5	43.0	36.7	--	--	--
	2,370	402	--	--	--	+0.8	+4.1	+1.1

* Broke in weld defect
F. M. 60 = Filler Metal No. 60
E = Electrode
W = Water
S = Sediment

Table 8. Chemical Composition of Other Nickel Alloys, Percent by Weight

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Cr	Ti	Mo	Cb	Other	Source
Ni-Cr-Fe 600	76.00	0.04	0.20	7.20	0.007	0.20	0.10	15.8	-	-	-	-	NCEL
Ni-Cr-Fe 600	75.26	0.06	0.18	7.25	0.008	0.27	0.38	16.0	-	-	-	-	NCEL 9/
Ni-Cr-Fe 600	76.0	-	-	7.0	-	-	-	16.0	-	-	-	-	INCO 7/
Filler Metal 62	73.5	0.04	0.20	7.50	0.007	0.30	0.03	16.0	-	-	2.3	-	NCEL
Filler Metal 82	72.0	0.02	3.00	1.00	0.007	0.20	0.02	20.0	0.5	-	2.5	-	NCEL
Electrode 132	74.0	0.05	0.75	8.50	0.005	0.20	0.10	14.0	-	-	2.0	0.1 Ce	NCEL
Electrode 182	68.0	0.05	7.50	7.50	0.005	0.60	0.10	14.0	-	-	2.0	0.1 Ce	NCEL
Ni-Cr-Fe 610	71.0	-	-	9.0	-	2.0	-	16.0	-	-	-	-	INCO 7/
Ni-Cr-Fe X750	73.41	0.08	0.55	6.90	0.003	0.36	0.09	14.50	2.40	-	0.90	0.81 Al	NCEL 9/
Ni-Cr-Fe X750	73.0	-	-	7.0	-	-	-	15.0	2.5	-	-	-	INCO 7/
Ni-Cr-Fe X750	73.0	0.04	0.70	6.75	0.007	0.30	0.05	15.0	2.50	-	0.85	0.80 Al	NCEL
Filler Metal 69	72.8	0.04	0.70	6.80	0.007	0.30	0.05	15.2	2.40	-	0.85	0.80 Al	NCEL
Filler Metal 718	52.5	0.04	0.20	18.0	0.007	0.20	0.10	19.0	0.80	3.0	-	-	NCEL
Ni-Cr-Fe 718	52.5	0.04	0.20	18.0	0.007	0.20	0.10	19.0	0.80	3.0	5.2	0.60 Al	NCEL
Ni-Cr-Fe 88	71.0	-	-	7.0	-	-	-	10.0	-	-	-	5.0 Sn 3.0 Bi	INCO 7/
Ni-Cr-Mo 3	58.0	-	-	3.00	-	-	-	19.0	-	19.0	-	-	INCO 7/
Ni-Co-Cr 700	46.0	-	-	1.0	-	-	-	15.0	-	3.75	-	28.5 Co 3.0 Al	INCO 7/
Ni-Cr-Mo 625	61.0	0.05	0.15	3.00	0.007	0.30	0.10	22.0	-	9.0	4.0	-	NCEL
Ni-Cr-Mo 625	63.0	-	-	-	-	-	-	22.0	-	9.0	-	-	INCO 7/
Ni-Fe-Cr 800	32.0	-	1.0	46.0	-	-	-	20.0	-	-	-	-	INCO 7/
Ni-Fe-Cr 800	32.0	0.04	0.75	46.0	0.007	0.35	0.30	20.5	-	-	-	-	NCEL
Filler Metal 82	72.0	0.02	3.00	1.00	0.007	0.20	0.04	20.0	0.55	-	2.5	-	NCEL
Electrode 138	38.0	0.16	1.90	27.0	0.008	0.40	0.40	28.0	-	3.60	-	1.0 W	NCEL
Ni-Fe-Cr 804	43.0	-	-	25.0	-	-	-	29.0	-	-	-	-	INCO 7/
Ni-Fe-Cr 825	41.12	0.05	0.82	30.86	0.01	0.31	1.61	21.12	1.00	2.94	-	0.14 Al	NCEL
Ni-Fe-Cr 825	41.8	0.03	0.65	30.0	0.007	0.35	1.80	21.5	0.90	3.0	-	0.15 Al	NCEL
Ni-Fe-Cr 825	42.0	-	-	30.0	-	-	2.0	22.0	-	3.0	-	-	INCO 7/
Filler Metal 65	42.0	0.03	0.80	30.0	0.008	0.30	1.70	21.0	0.90	3.0	-	-	NCEL

Table 8. (continued)

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Cr	Ti	Mo	Cb	Other	Source
Electrode 135	38.0	0.05	0.50	31.0	0.008	0.40	1.80	19.0	-	5.5	1.0	-	NCEL
Ni-Fe-Cr 825Cb	42.0	-	-	30.0	-	-	2.0	22.0	-	3.0	-	-	INCO [7]
Ni-Fe-Cr 901	43.0	-	-	34.0	-	-	-	14.0	-	-	-	-	INCO [7]
Ni-Fe-Cr 902	42.0	0.02	0.40	48.5	0.008	0.50	0.05	5.4	2.40	-	-	0.65 Al	NCEL
Ni-Cr-Fe-Mo "F"	46.0	-	-	21.0	-	-	-	22.0	-	7.0	-	-	INCO [7]
Ni-Cr-Fe-Mo "G"	45.0	-	-	20.0	-	-	2.00	21.0	-	7.0	-	2.5 Co 1.0 W	INCO [7]
Ni-Cr-Fe-Mo "X"	60.0	-	-	19.0	-	-	-	22.0	-	9.0	-	-	INCO [7]
Ni-Cr-Co "41"	55.29	0.11	<0.01	0.33	-	0.07	-	19.08	3.34	9.72	-	11.47 Co	NCEL [9]
Ni-Mo-Fe "B"	60.0	-	-	5.0	-	-	-	-	-	26.0	-	-	INCO [7]
Ni-Mo-Cr "C"	55.68	0.05	0.52	6.32	0.009	0.62	-	15.33	-	16.71	-	3.53 W 0.96 Co 0.26 V 0.010 P	NCEL
Ni-Mo-Cr "C"	60.0	-	-	5.0	-	-	-	15.0	-	16.0	-	4.0 W	INCO [7]
Ni-Sn-Zn 73	79.0	-	2.0	-	-	-	-	-	-	-	-	8.0 Sn 7.0 Zn 4.0 Pb	INCO [7]
Ni-Be	97.55	-	-	-	-	-	-	-	-	-	-	1.95 Be	NCEL
Ni-Cr 65-35	65.0	-	-	-	-	-	-	35.0	-	-	-	-	INCO [7]
Ni-Cr 75	78.0	-	-	-	-	-	-	20.0	-	-	-	-	INCO [7]
Ni-Cr 80-20	80.0	-	-	-	-	-	-	20.0	-	-	-	-	INCO [7]
Ni-Mo 2	66.0	-	-	2.0	-	-	-	-	-	30.0	-	-	INCO [7]
Ni-Si "D"	86.0	-	-	-	-	10.0	3.0	-	-	-	-	-	INCO [7]

Numbers under source are references at end of paper.

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys

Alloy	Environment 1/	Exposure, Days	Depth, Feet	Corrosion Rate, 2/ MPY	Corrosion Crevice, Mils	Type of 4/ Corrosion	Source 3/
Ni-Cr-Fe 600	W	123	5,640	<0.1	4	C	INCO 7/
Ni-Cr-Fe 600	S	123	5,640	<0.1	3	C	INCO 7/
Ni-Cr-Fe 600	W	403	6,780	0.1	23	C	INCO 7/
Ni-Cr-Fe 600	S	403	6,780	0.3	----	I C	INCO 7/
Ni-Cr-Fe 600	W	751	5,640	<0.1	33	C	INCO 7/
Ni-Cr-Fe 600	S	751	5,640	<0.1	4	C, P	INCO 7/
Ni-Cr-Fe 600	W	1,064	5,300	0.1	35(PR) 4/	C	INCO 7/
Ni-Cr-Fe 600	S	1,064	5,300	<0.1	2	C	INCO 7/
Ni-Cr-Fe 600	W	1,064	5,300	0.5	51	C, P	NCEL 9/
Ni-Cr-Fe 600	W	197	2,340	0.2	15	C	INCO 7/
Ni-Cr-Fe 600	S	197	2,340	0.1	10	C	INCO 7/
Ni-Cr-Fe 600	W	402	2,370	0.0	----	SL ET	NCEL
Ni-Cr-Fe 600	W	402	2,370	0.1	28	C	INCO 7/
Ni-Cr-Fe 600	W	402	2,370	0.0	----	I P 7/	NCEL
Ni-Cr-Fe 600, welded, 132 electrode	W	402	2,370	0.3	----	ET	NCEL
Ni-Cr-Fe 600, welded, 182 electrode	W	402	2,370	<0.1	----	ET	NCEL
Ni-Cr-Fe 600, welded, 62 electrode	W	402	2,370	0.4	----	8/	NCEL
Ni-Cr-Fe 600, welded, 82 electrode	W	402	2,370	0.3	----	9/	NCEL
Ni-Cr-Fe 600	S	402	2,370	0.0	----	ET	NCEL
Ni-Cr-Fe 600	S	402	2,370	0.1	----	T to PR,125	NCEL
Ni-Cr-Fe 600	S	402	2,370	<0.1	----	I C	INCO 7/

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion		Type of Corrosion[4]	Source[3]
				Rate,[2] MPY	Crevice, Mils		
Cast, Ni-Cr-Fe 610	W	123	5,640	0.3	4	C	INCO[7]
Cast, Ni-Cr-Fe 610	S	123	5,640	0.1	2	C	INCO[7]
Cast, Ni-Cr-Fe 610	W	403	6,780	<0.1	----	I C	INCO[7]
Cast, Ni-Cr-Fe 610	S	403	6,780	0.1	----	I C	INCO[7]
Cast, Ni-Cr-Fe 610	W	751	5,640	0.6	83	C	INCO[7]
Cast, Ni-Cr-Fe 610	S	751	5,640	0.3	5	C	INCO[7]
Cast, Ni-Cr-Fe 610	W	1,064	5,300	0.9	----	I P	INCO[7]
Cast, Ni-Cr-Fe 610	S	1,064	5,300	<0.1	13	C	INCO[7]
Cast, Ni-Cr-Fe 610	W	197	2,340	0.2	2	C	INCO[7]
Cast, Ni-Cr-Fe 610	S	197	2,340	<0.1	3	C	INCO[7]
Cast, Ni-Cr-Fe 610	W	402	2,370	0.3	18	C	INCO[7]
Cast, Ni-Cr-Fe 610	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Cr-Fe X750	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Fe X750	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Fe X750	W	403	6,780	0.2	35(PR)	C	INCO[7]
Ni-Cr-Fe X750	S	403	6,780	<0.1	3	C	INCO[7]
Ni-Cr-Fe X750	W	751	5,640	0.4	40(PR)	C	INCO[7]
Ni-Cr-Fe X750	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Fe X750	W	1,064	5,300	0.1	40(PR)	C, P to 25m	INCO[7]
Ni-Cr-Fe X750	W	1,064	5,300	0.1	47	C	NCEL[9]
Ni-Cr-Fe X750	S	1,064	5,300	<0.1	9	C	INCO[7]
Ni-Cr-Fe X750	W	197	2,340	0.4	18	C	INCO[7]
Ni-Cr-Fe X750	S	197	2,340	<0.1	7	C	INCO[7]
Ni-Cr-Fe X750	W	402	2,370	0.1	17	C	INCO[7]
Ni-Cr-Fe X750	W	402	2,370	0.1	----	T	NCEL
Ni-Cr-Fe X750, welded, 69 electrode	W	402	2,370	0.3	----	ET	NCEL
Ni-Cr-Fe X750, welded, 718 electrode	W	402	2,370	0.2	----	10/	NCEL

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion		Type of Corrosion[4]	Source[3]
				Rate,[2] MPY	Crevice, Mils		
Ni-Cr-Fe X750	S	402	2,370	<0.1	----	ET	NCEL
Ni-Cr-Fe X750	S	402	2,370	<0.1	4	C	INCO[7]
Ni-Cr-Fe 718	W	402	2,370	<0.1	----	NC	NCEL
Ni-Cr-Fe 718, welded, 718 electrode	W	402	2,370	0.0	----	NC	NCEL
Ni-Cr-Fe 88	W	123	5,640	0.1	4	C	INCO[7]
Ni-Cr-Fe 88	S	123	5,640	0.1	----	NC	INCO[7]
Ni-Cr-Fe 88	W	403	6,780	<0.1	5	C	INCO[7]
Ni-Cr-Fe 88	S	403	6,780	<0.1	----	NC	INCO[7]
Ni-Cr-Fe 88	W	751	5,640	<0.1	----	I C	INCO[7]
Ni-Cr-Fe 88	S	751	5,640	1.3	----	[11]	INCO[7]
Ni-Cr-Fe 88	W	1,064	5,300	<0.1	67	C	INCO[7]
Ni-Cr-Fe 88	S	1,064	5,300	<0.1	5	C	INCO[7]
Ni-Cr-Fe 88	W	197	2,340	0.3	17	C, P	INCO[7]
Ni-Cr-Fe 88	S	197	2,340	<0.1	----	I C	INCO[7]
Ni-Cr-Fe 88	W	402	2,370	0.4	52	C, P	INCO[7]
Ni-Cr-Fe 88	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Cr-Mo 3	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	W	403	6,780	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	S	403	6,780	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	W	751	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	W	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	S	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Cr-Mo 3	W	197	2,340	<0.1	----	NC	INCO[7]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment 1/	Exposure, Days	Depth, Feet	Corrosion: Rate, MPY 2/	Corrosion: Crevice, Mils	Type of Corrosion 4/	Source 3/
Ni-Cr-Mo 3	S	197	2,340	<0.1	----	NC	INCO 7/
Ni-Cr-Mo 3	W	402	2,370	<0.1	----	NC	INCO 7/
Ni-Cr-Mo 3	S	402	2,370	<0.1	----	NC	INCO 7/
Ni-Cr-Mo 625	W	402	2,370	<0.1	----	NC	NCEL 7/
Ni-Cr-Mo 625	W	402	2,370	<0.1	----	NC	INCO 7/
Ni-Cr-Mo 625	S	402	2,370	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	W	123	5,640	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	S	123	5,640	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	W	403	6,780	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	S	403	6,780	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	W	751	5,640	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	S	751	5,640	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	W	1,064	5,300	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	S	1,064	5,300	<0.1	----	I C	INCO 7/
Ni-Co-Cr 700	W	197	2,340	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	S	197	2,340	<0.1	----	NC	INCO 7/
Ni-Co-Cr 700	W	402	2,370	<0.1	----	I C	INCO 7/
Ni-Co-Cr 700	S	402	2,370	<0.1	----	I C	INCO 7/
Ni-Fe-Cr 800	W	123	5,640	<0.1	----	NC	INCO 7/
Ni-Fe-Cr 800	S	123	5,640	<0.1	----	NC	INCO 7/
Ni-Fe-Cr 800	W	403	6,780	<0.1	----	NC	INCO 7/
Ni-Fe-Cr 800	S	403	6,780	<0.1	1	C	INCO 7/
Ni-Fe-Cr 800	W	751	5,640	<0.1	----	NC	INCO 7/
Ni-Fe-Cr 800	S	751	5,640	<0.1	----	NC	INCO 7/
Ni-Fe-Cr 800	W	1,064	5,300	<0.1	----	NC	INCO 7/
Ni-Fe-Cr 800	S	1,064	5,300	<0.1	6	C	INCO 7/

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion: Rate,[2] MPY	Corrosion: Crevice, Mils	Type of Corrosion[4]	Source[3]
Ni-Fe-Cr 800	W	197	2,340	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 800	S	197	2,340	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 800	W	402	2,370	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 800	W	402	2,370	0.0	----	NC	NCEL
Ni-Fe-Cr 800, welded, 82 electrode	W	402	2,370	<0.1	----	12/	NCEL
Ni-Fe-Cr 800, welded, 138 electrode	W	402	2,370	<0.1	----	13/	NCEL
Ni-Fe-Cr 800	S	402	2,370	<0.1	----	ET	NCEL
Ni-Fe-Cr 800	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 804	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 804	W	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	W	751	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 804	S	751	5,640	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	W	1,064	5,300	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	S	1,064	5,300	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	W	197	2,340	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	S	197	2,340	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	W	402	2,370	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 804	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825	W	123	5,640	0.0	----	NC	NCEL
Ni-Fe-Cr 825	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825	S	123	5,640	<0.1	----	NC	NCEL

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of[4] Corrosion	Source[3]
Ni-Fe-Cr 825	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825	W	403	6,780	0.0	----	NC	NCEL
Ni-Fe-Cr 825	W	403	6,780	<0.1	----	IC	INCO[7]
Ni-Fe-Cr 825	S	403	6,780	0.0	----	NC	NCEL
Ni-Fe-Cr 825	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825	W	751	5,640	0.0	22	C	NCEL
Ni-Fe-Cr 825	W	751	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825	W	1,064	5,300	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825	S	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825	W	197	2,340	0.0	----	NC	NCEL
Ni-Fe-Cr 825	W	197	2,340	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825	S	197	2,340	0.0	8	C	NCEL
Ni-Fe-Cr 825	S	197	2,340	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825	W	402	2,370	<0.1	15	C	NCEL
Ni-Fe-Cr 825	W	402	2,370	<0.1	----	ET	NCEL
Ni-Fe-Cr 825	W	402	2,370	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825, welded, 135 electrode	W	402	2,370	<0.1	----	[14]	NCEL
Ni-Fe-Cr 825, welded, 65 electrode	W	402	2,370	<0.1	----	NC	NCEL
Ni-Fe-Cr 825	S	402	2,370	0.0	8	C	NCEL
Ni-Fe-Cr 825	S	402	2,370	<0.1	----	NC	NCEL
Ni-Fe-Cr 825	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825S[5]	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825S	S	123	5,640	<0.1	----	NC	INCO[7]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion: Rate,[2] MPY	Corrosion: Crevice, Mils	Type of Corrosion[4]	Source[3]
Ni-Fe-Cr 825S	W	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825S	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825S	W	751	5,640	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825S	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825S	W	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825S	S	1,064	5,300	<0.1	4	C	INCO[7]
Ni-Fe-Cr 825S	W	197	2,340	<0.1	----	I C, I P	INCO[7]
Ni-Fe-Cr 825S	S	197	2,340	<0.1	----	I C, I P	INCO[7]
Ni-Fe-Cr 825S	W	402	2,370	<0.1	----	I C, I P	INCO[7]
Ni-Fe-Cr 825S	S	402	2,370	<0.1	----	I C, I P	INCO[7]
Ni-Fe-Cr 825Cb	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	W	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825Cb	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825Cb	W	751	5,640	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 825Cb	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	W	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	S	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	W	197	2,340	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	S	197	2,340	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	W	402	2,370	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 825Cb	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Fe Cr 901	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 901	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Fe-Cr 901	W	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 901	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Fe-Cr 901	W	751	5,640	<0.1	----	NC	INCO[7]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1/]	Exposure, Days	Depth, Feet	Corrosion Rate,[2/] MPY	Corrosion Crevice, Mils	Type of[4/] Corrosion	Source[3/]
Ni-Fe-Cr 901	S	751	5,640	<0.1	----	I C	INCO[7/]
Ni-Fe-Cr 901	W	1,064	5,300	<0.1	----	NC	INCO[7/]
Ni-Fe-Cr 901	S	1,064	5,300	<0.1	----	NC	INCO[7/]
Ni-Fe-Cr 901	W	197	2,340	<0.1	----	NC	INCO[7/]
Ni-Fe-Cr 901	S	197	2,340	<0.1	----	I C	INCO[7/]
Ni-Fe-Cr 901	W	402	2,370	<0.1	----	I C	INCO[7/]
Ni-Fe-Cr 901	S	402	2,370	<0.1	----	I C	INCO[7/]
Ni-Fe-Cr 902[6/]	W	402	2,370	1.4	35	C, I P	NCEL
Ni-Fe-Cr 902[6/]	S	402	2,370	1.0	20	C, I P	NCEL
Ni-Cr-Fe-Mo F	W	123	5,640	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	S	123	5,640	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	W	403	6,780	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	S	403	6,780	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	W	751	5,640	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	S	751	5,640	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	W	1,064	5,300	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	S	1,064	5,300	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	W	197	2,340	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	S	197	2,340	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	W	402	2,370	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo F	S	402	2,370	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo G	W	402	2,370	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo G	S	402	2,370	<0.1	----	NC	INCO[7/]
Ni-Cr-Fe-Mo X	W	123	5,640	<0.1	----	NC	INCO[7/]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of[4] Corrosion	Source[3]
Ni-Cr-Fe-Mo X	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	W	403	6,780	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	S	403	6,780	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	W	751	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	W	1,064	5,300	<0.1	----	SL ET	INCO[7]
Ni-Cr-Fe-Mo X	S	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	W	197	2,340	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	S	197	2,340	<0.1	----	I C	INCO[7]
Ni-Cr-Fe-Mo X	W	402	2,370	<0.1	----	NC	INCO[7]
Ni-Cr-Fe-Mo X	S	402	2,370	<0.1	----	NC	INCO[7]
Ni-Cr-Co 41	W	1,064	5,300	0.0	----	NC	NCEL[9]
Ni-Mo-Fe B	W	123	5,640	2.3	----	U	INCO[7]
Ni-Mo-Fe B	S	123	5,640	2.2	----	U	INCO[7]
Ni-Mo-Fe B	W	403	6,780	4.0	----	U	INCO[7]
Ni-Mo-Fe B	S	403	6,780	0.6	----	15/	INCO[7]
Ni-Mo-Fe B	W	751	5,640	2.9	----	G	INCO[7]
Ni-Mo-Fe B	S	751	5,604	1.8	----	G	INCO[7]
Ni-Mo-Fe B	W	1,064	5,300	1.5	----	G	INCO[7]
Ni-Mo-Fe B	S	1,064	5,300	0.8	----	Nu	INCO[7]
Ni-Mo-Fe B	W	197	2,340	<0.1	----	Nu ET	INCO[7]
Ni-Mo-Fe B	S	197	2,340	<0.1	----	I C, I P	INCO[7]
Ni-Mo-Fe B	W	402	2,370	1.2	----	G	INCO[7]
Ni-Mo-Fe B	S	402	2,370	0.2	----	U	INCO[7]
Ni-Mo-Cr C	W	123	5,640	<0.1	----	NC	NCEL

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of Corrosion[4]	Source[3]
Ni-Mo-Cr C	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	S	123	5,640	<0.1	----	NC	NCEL[7]
Ni-Mo-Cr C	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	W	403	6,780	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	W	403	6,780	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	S	403	6,780	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	S	403	6,780	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	W	751	5,640	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	W	751	5,640	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	S	751	5,640	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	S	751	5,640	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	W	1,064	5,300	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	W	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	S	1,064	5,300	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	S	1,064	5,300	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	W	197	2,340	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	W	197	2,340	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	S	197	2,340	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	S	197	2,340	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	W	402	2,370	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	W	402	2,370	<0.1	----	NC	INCO[7]
Ni-Mo-Cr C	S	402	2,370	0.0	----	NC	NCEL[7]
Ni-Mo-Cr C	S	402	2,370	<0.1	----	NC	INCO[7]
Ni-Sn-Zn 23	W	123	5,640	2.6	25	C	INCO[7]
Ni-Sn-Zn 23	S	123	5,640	1.8	14	C	INCO[7]
Ni-Sn-Zn 23	W	403	6,780	8.4	35	C, P	INCO[7]
Ni-Sn-Zn 23	S	403	6,780	<0.1	----	NC	INCO[7]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion		Type of Corrosion[4]	Source[3]
				Rate,[2] MPY	Crevice, Mils		
Ni-Sn-Zn 23	W	751	5,640	3.5	56	C, P	INCO[7]
Ni-Sn-Zn 23	S	751	5,640	2.1	52	C, P	INCO[7]
Ni-Sn-Zn 23	W	1,064	5,300	1.7	50	C, P	INCO[7]
Ni-Sn-Zn 23	S	1,064	5,300	1.0	----	P, 35m	INCO[7]
Ni-Sn-Zn 23	W	197	2,340	0.5	15	C	INCO[7]
Ni-Sn-Zn 23	S	197	2,340	<0.1	----	I C	INCO[7]
Ni-Sn-Zn 23	W	402	2,370	0.9	29	C	INCO[7]
Ni-Sn-Zn 23	S	402	2,370	0.1	----	I C	INCO[7]
Ni-Be	W	402	2,370	1.1	----	[16]	NCEL
Ni-Be	S	402	2,370	0.7	----	[17]	NCEL
Ni-Cr 65-35	W	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr 65-35	S	123	5,640	<0.1	----	NC	INCO[7]
Ni-Cr 65-35	W	403	6,780	<0.1	35(PR)	C	INCO[7]
Ni-Cr 65-35	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Cr 65-35	W	751	5,640	<0.1	20	C	INCO[7]
Ni-Cr 65-35	S	751	5,640	<0.1	----	I C	INCO[7]
Ni-Cr 65-35	W	1,064	5,300	<0.1	5	C	INCO[7]
Ni-Cr 65-35	S	1,064	5,300	0.1	50(PR)	C	INCO[7]
Ni-Cr 65-35	W	197	2,340	0.3	24	C	INCO[7]
Ni-Cr 65-35	S	197	2,340	<0.1	----	I C	INCO[7]
Ni-Cr 65-35	W	402	2,370	0.1	6	C	INCO[7]
Ni-Cr 65-35	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Cr 75	W	123	5,640	<0.1	----	I C	INCO[7]
Ni-Cr 75	S	123	5,640	<0.1	----	NC	INCO[7]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion Rate,[2] MPY	Corrosion Crevice, Mils	Type of Corrosion[4]	Source[3]
Ni-Cr 75	W	403	6,780	0.4	40(PR)	C	INCO[7]
Ni-Cr 75	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Cr 75	W	751	5,640	0.5	40(PR)	C, P	INCO[7]
Ni-Cr 75	S	751	5,640	<0.1	2	C	INCO[7]
Ni-Cr 75	W	1,064	5,300	<0.1	----	I C	INCO[7]
Ni-Cr 75	S	1,064	5,300	<0.1	12	C	INCO[7]
Ni-Cr 75	W	197	2,340	0.3	40(PR)	C	INCO[7]
Ni-Cr 75	S	197	2,340	<0.1	5	C	INCO[7]
Ni-Cr 75	W	402	2,370	0.4	40(PR)	C, P	INCO[7]
Ni-Cr 75	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Cr 80-20	W	123	5,640	<0.1	2	C	INCO[7]
Ni-Cr 80-20	S	123	5,640	<0.1	----	I C	INCO[7]
Ni-Cr 80-20	W	403	6,780	0.2	11	C	INCO[7]
Ni-Cr 80-20	S	403	6,780	<0.1	----	I C	INCO[7]
Ni-Cr 80-20	W	751	5,640	0.4	32(PR)	C	INCO[7]
Ni-Cr 80-20	S	751	5,640	<0.1	----	I C	INCO[7]
Ni-Cr 80-20	W	1,064	5,300	<0.1	5	C	INCO[7]
Ni-Cr 80-20	S	1,064	5,300	0.1	50(PR)	C	INCO[7]
Ni-Cr 80-20	W	197	2,340	0.2	32(PR)	C	INCO[7]
Ni-Cr 80-20	S	197	2,340	<0.1	----	I C, E	INCO[7]
Ni-Cr 80-20	W	402	2,370	0.2	18	C, P	INCO[7]
Ni-Cr 80-20	S	402	2,370	<0.1	----	I C	INCO[7]
Ni-Mo 2	W	123	5,640	1.2	----	G	INCO[7]
Ni-Mo 2	S	123	5,640	1.1	----	G	INCO[7]
Ni-Mo 2	W	403	6,780	2.2	----	G	INCO[7]

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

Alloy	Environment[1]	Exposure, Days	Depth, Feet	Corrosion: Rate,[2] MPY	Corrosion: Crevice, Mils	Type of[4] Corrosion	Source[3]
Ni-Mo 2	S	403	6,780	0.3	----	G	INCO[7]
Ni-Mo 2	W	751	5,640	6.8	----	G	INCO[7]
Ni-Mo 2	S	751	5,640	1.6	----	G	INCO[7]
Ni-Mo 2	W	1,064	5,300	3.2	----	G	INCO[7]
Ni-Mo 2	S	1,064	5,300	1.8	----	G	INCO[7]
Ni-Mo 2	W	197	2,340	1.0	----	U	INCO[7]
Ni-Mo 2	S	197	2,340	0.2	----	G	INCO[7]
Ni-Mo 2	W	402	2,370	1.6	----	G	INCO[7]
Ni-Mo 2	S	402	2,370	0.3	----	ET	INCO[7]
Ni-Si D	W	123	5,640	1.3	12	C	INCO[7]
Ni-Si D	S	123	5.640	1.4	10	C	INCO[7]
Ni-Si D	W	403	6,780	2.4	5	C, P	INCO[7]
Ni-Si D	S	403	6,780	1.4	14	C	INCO[7]
Ni-Si D	W	751	5,640	1.7	29	C	INCO[7]
Ni-Si D	S	751	5,640	1.5	6	C, P	INCO[7]
Ni-Si D	W	1,064	5,300	1.6	42	C, P to 38m	INCO[7]
Ni-Si D	S	1,064	5,300	1.1	25	C, P to 20m	INCO[7]
Ni-Si D	W	197	2,340	0.2	----	I C	INCO[7]
Ni-Si D	S	197	2,340	<0.1	----	I C	INCO[7]
Ni-Si D	W	402	2,370	0.5	14	C	INCO[7]
Ni-Si D	S	402	2,370	0.2	----	ET	INCO[7]

[1] W = specimens exposed on sides of STU in sea water

S = specimens exposed in base of STU, partially embedded in bottom sediments

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

2/ MPY = mils penetration per year calculated from weight loss

3/ Numbers refer to references at end of paper

4/ Symbols for Type of Corrosion

C - crevice	P - pitting
E - edge	PR - perforation
ET - etched	SL - slight
G - general	T - tunneling
I - Incipient	U - uniform
NC - no visible corrosion	
Nu - non uniform	

Numbers indicate mils:

i.e., 20m = 20 mils maximum
14.6a = 14.6 mils average
20 = 20 mils

5/ S = sensitized for 1 hour at 1200°F

6/ 1" x 6" specimens

7/ Weld bead perforated

Table 9. Corrosion Rates and Types of Corrosion of Nickel Alloys (cont'd)

8/ Weld bead perforated, line corrosion at edge of weld bead.

9/ Weld bead perforated, line corrosion at edge of weld bead, tunneling to perforation in heat affected zone.

10/ Tunneling in heat affected zone parallel to weld bead (55 mils deep) and away from weld, perforated at edge of weld bead.

11/ Single pit to perforation, 180 mils.

12/ Edge penetration at weld.

13/ Line corrosion at edge of weld bead

14/ One end of weld corroded

15/ Groove at mud line, 4 mils

16/ Surface of bars etched, pitting on ends to 17 mils.

17/ Surface of bars etched, pitting on ends to 8 mils.

Table 10. Stress Corrosion Test Results

Alloy	Stress, (ksi)	% of Yield Strength	Exposure, (days)	Depth, (ft)	Number of Specimens	Number Failed
Ni-Mo-Cr C	21.0	35	123	5,640	3	0
Ni-Mo-Cr C	30.0	50	123	5,640	3	0
Ni-Mo-Cr C	45.0	75	123	5,640	3	0
Ni-Mo-Cr C	21.0	35	403	6,780	2	0
Ni-Mo-Cr C	30.0	50	403	6,780	2	0
Ni-Mo-Cr C	45.0	75	403	6,780	2	0
Ni-Mo-Cr C	21.0	35	751	5,640	3	0
Ni-Mo-Cr C	30.0	50	751	5,640	3	0
Ni-Mo-Cr C	45.0	75	751	5,640	3	0
Ni-Mo-Cr C	21.0	35	197	2,340	3	0
Ni-Mo-Cr C	30.0	50	197	2,340	3	0
Ni-Mo-Cr C	45.0	75	197	2,340	3	0
Ni-Mo-Cr C	30.0	50	402	2,370	3	0
Ni-Mo-Cr C	45.0	75	402	2,370	3	0
Ni-Fe-Cr 825	25.7	50	402	2,370	3	0
Ni-Fe-Cr 825	38.5	75	402	2,370	3	0

Table 11. Charges in Mechanical Properties of Nickel Alloys Due to Corrosion

Alloy	Exposure		Original Properties			Percent Change		
	Depth, Feet	Days	Tensile Strength, KSI	Yield Strength KSI	Elonga-tion, Percent	Tensile Strength	Yield Strength	Elonga-tion
Ni-Fe-Cr 825	-	-	108.1	52.3	37.8			
	5,640	123				+0.4	+3.8	0.0
	6,780	403				+0.3	+2.7	-3.5
	5,640	751				+1.5	+4.9	-2.6
	2,340	197				+0.4	+3.9	-5.8
	2,370	402				+0.7	+3.9	-3.3
Ni-Mo-Cr C	-	-	120.8	60.0	43.0			
	5,640	123				+3.0	+4.5	-0.5
	6,780	403				+4.7	+1.4	+15.1
	5,640	751				+4.4	-0.2	+14.8
	5,300	1,064				+3.4	-7.4	+14.9
	2,340	197				+3.1	-0.5	+18.1
	2,370	402				+3.2	+3.0	+11.9
Ni-Fe-Cr 902	-	-	98.9	40.3	43.2			
	2,370	402				-1.5	-8.2	-49.1

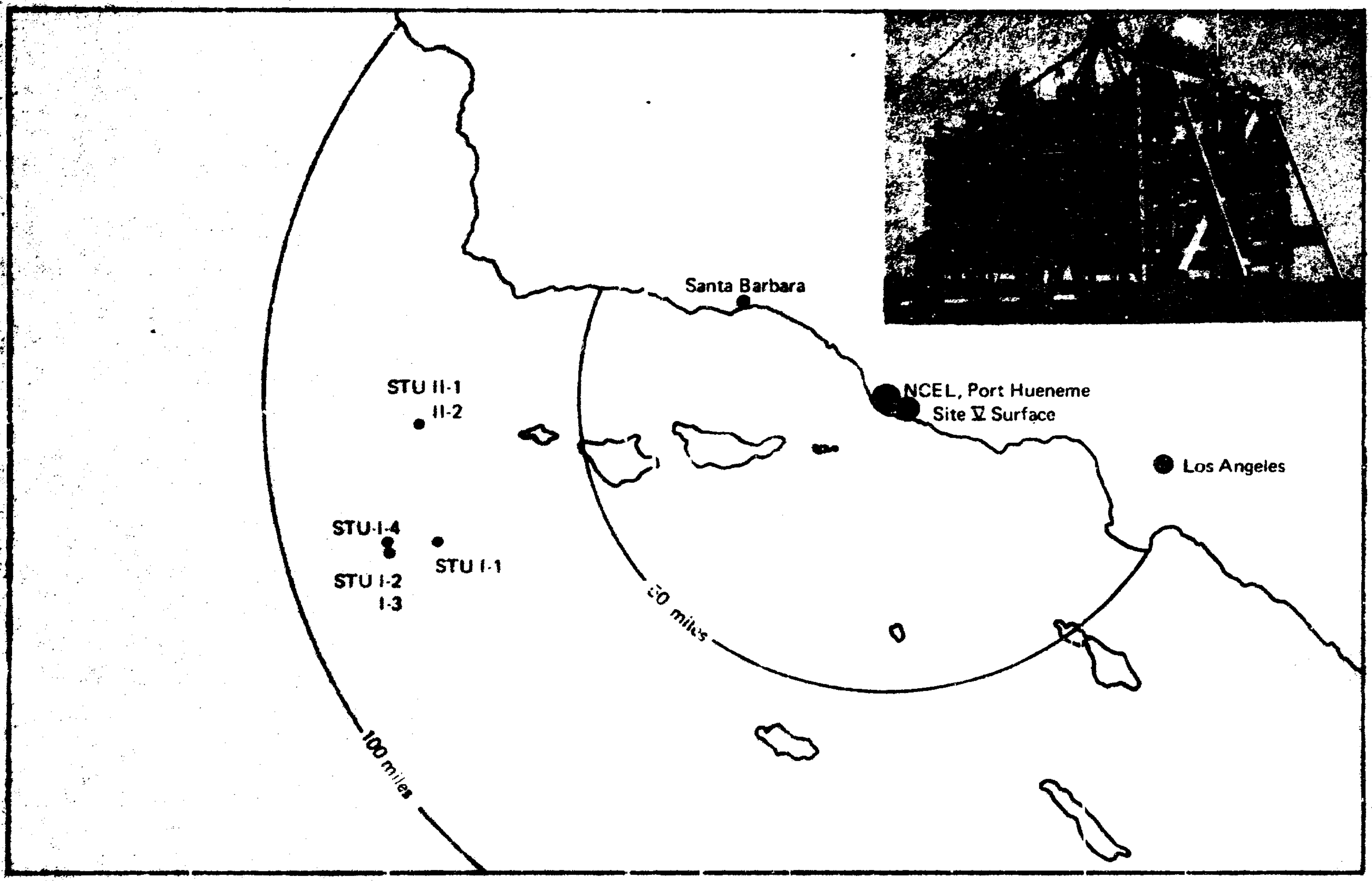

Figure 1. Area map showing STU sites off the Pacific Coast; STU structure in inset.

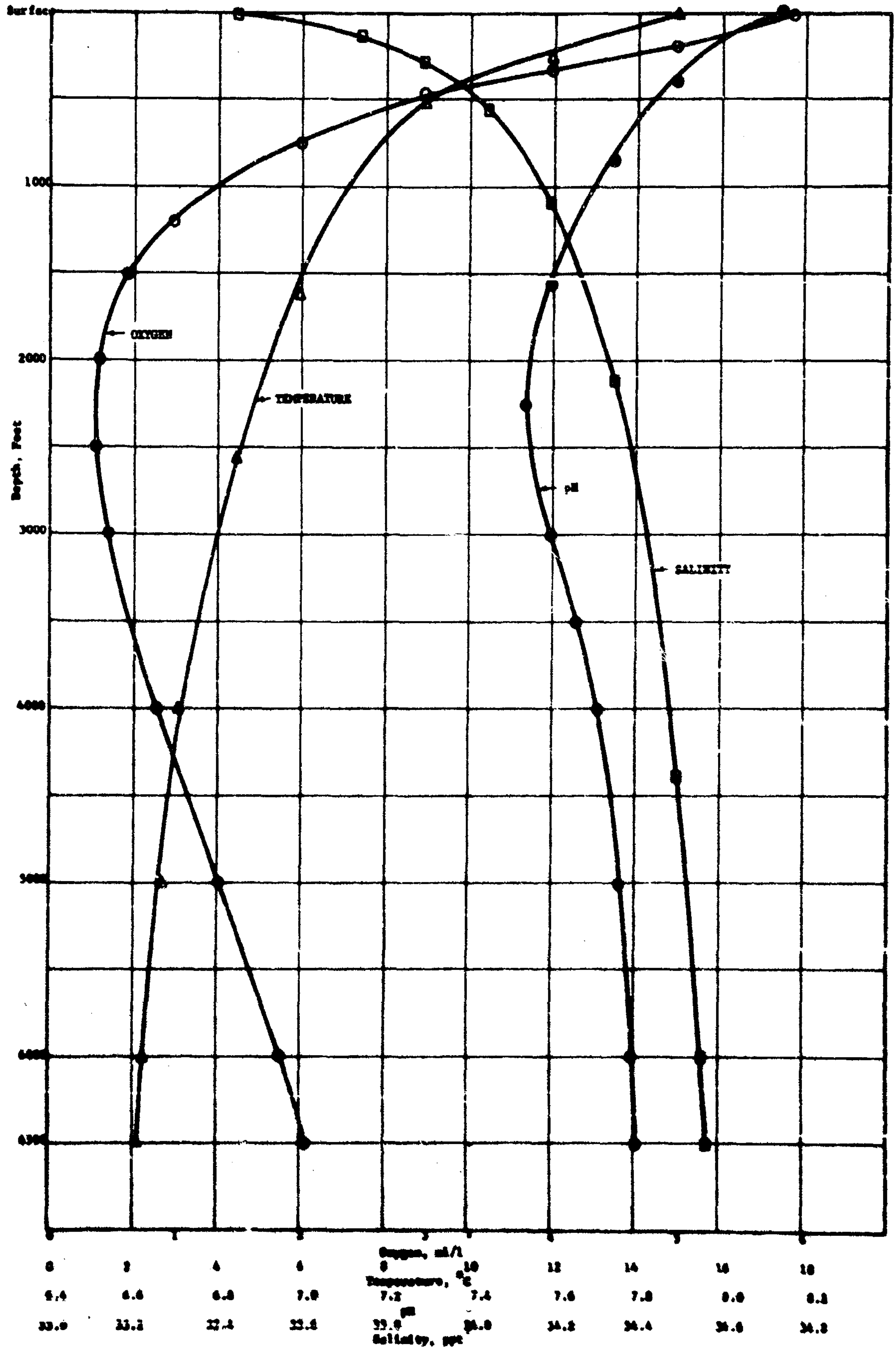

Figure 3. Oceanographic data at STU sites.

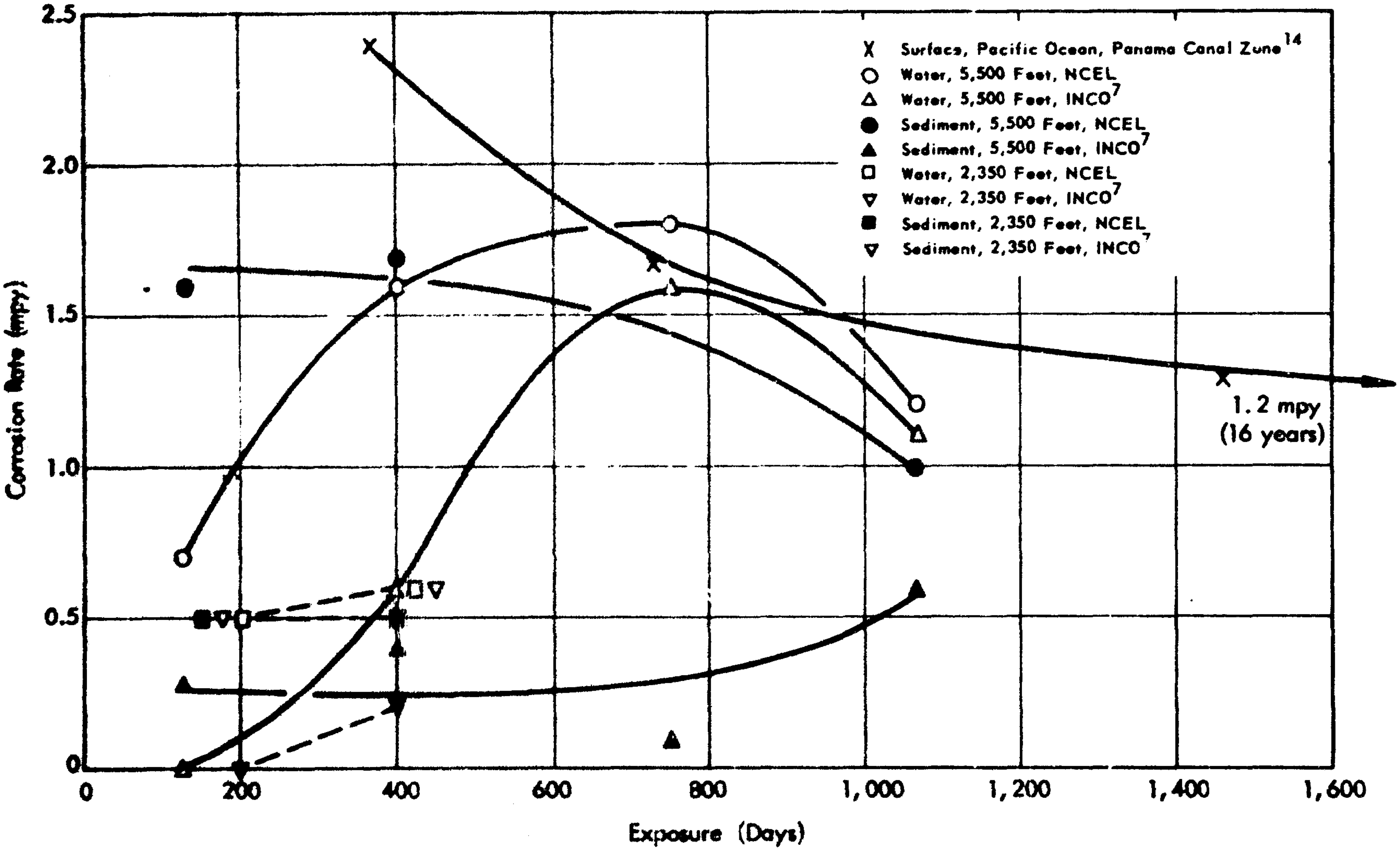

Figure 3. Corrosion of nickel 200 in sea water.

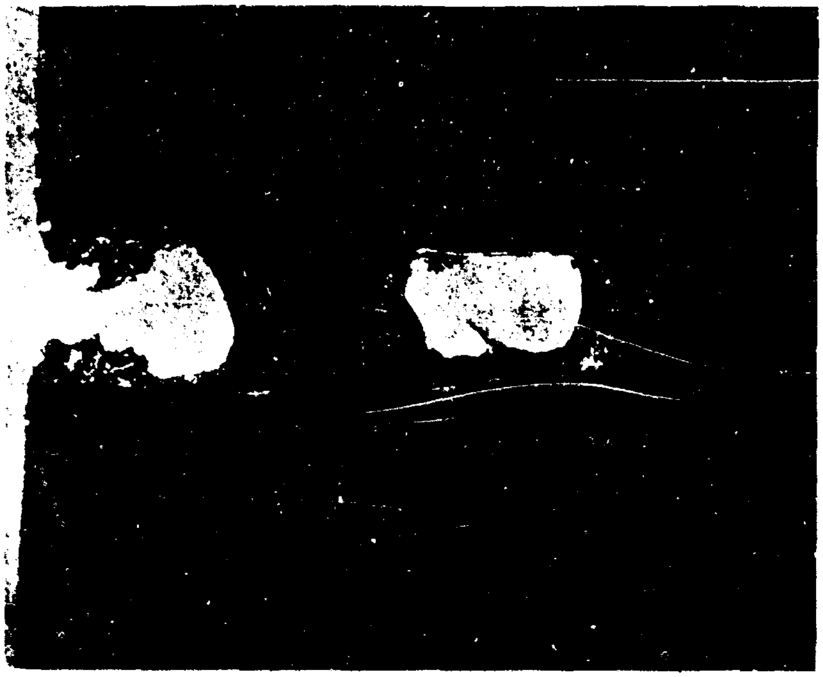

Figure 4. Corrosion of weld bead on nickel made with electrode 61 exposed in sea water for 402 days at a depth of 2,370 feet.

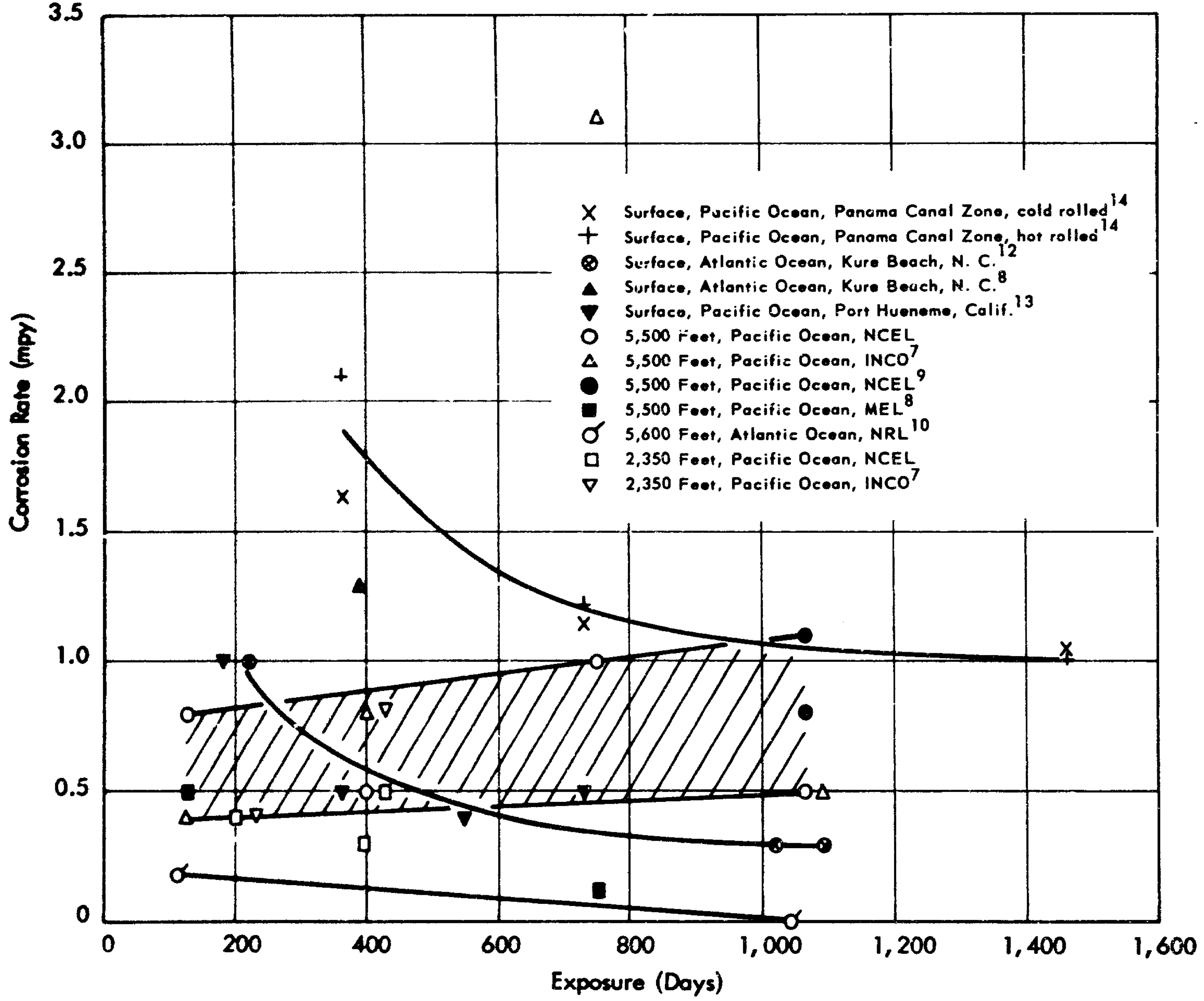

Figure 5. Corrosion of nickel–copper alloy 400 in sea water.

Figure 6. Pitting corrosion of nickel-copper alloy 400 after 1064 days of exposure at a depth of 5300 feet.

Figure 7. Corrosion of weld bead on nickel-copper alloy 400 made with electrode 60 exposed in sea water for 402 days at a depth of 2,370 feet.

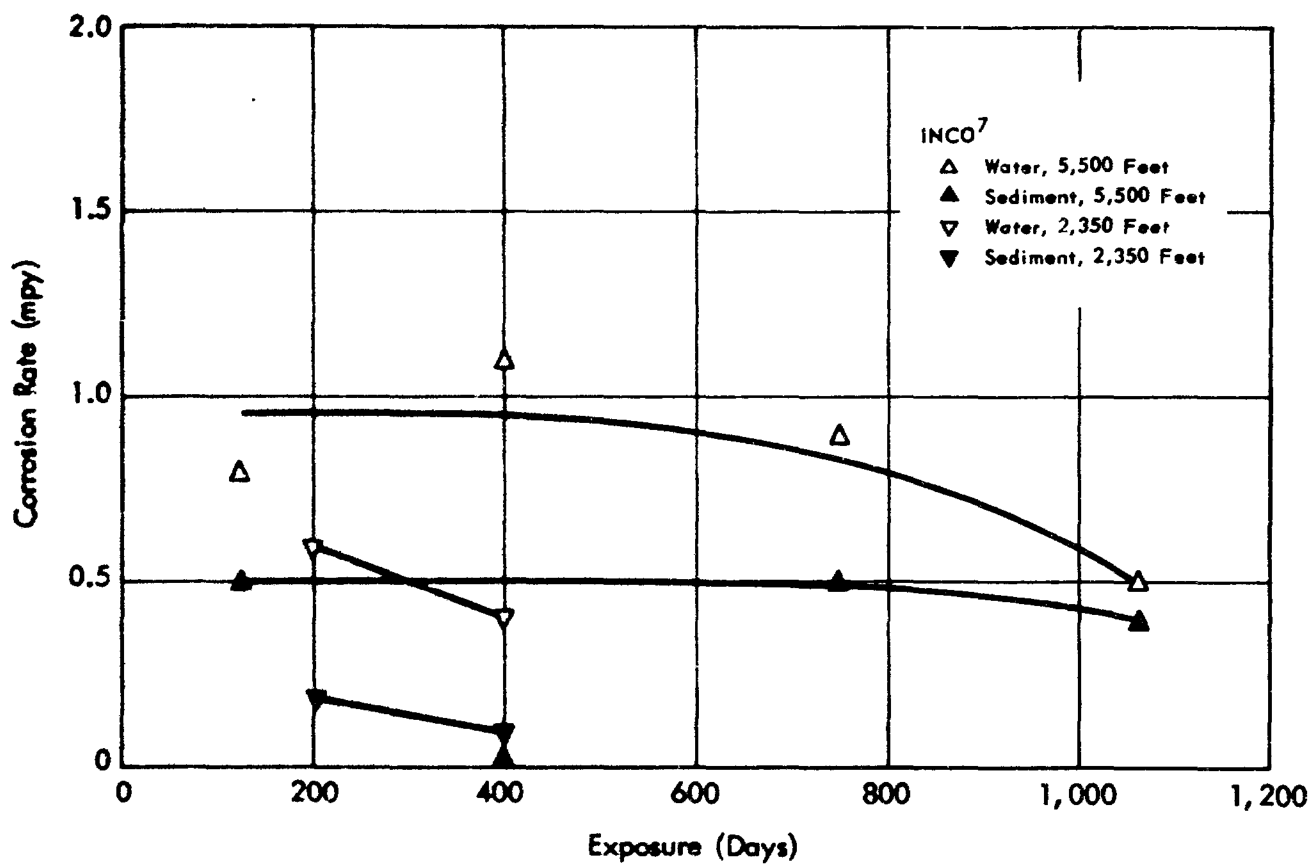

Figure 8. Corrosion of cast nickel-copper alloy 410.

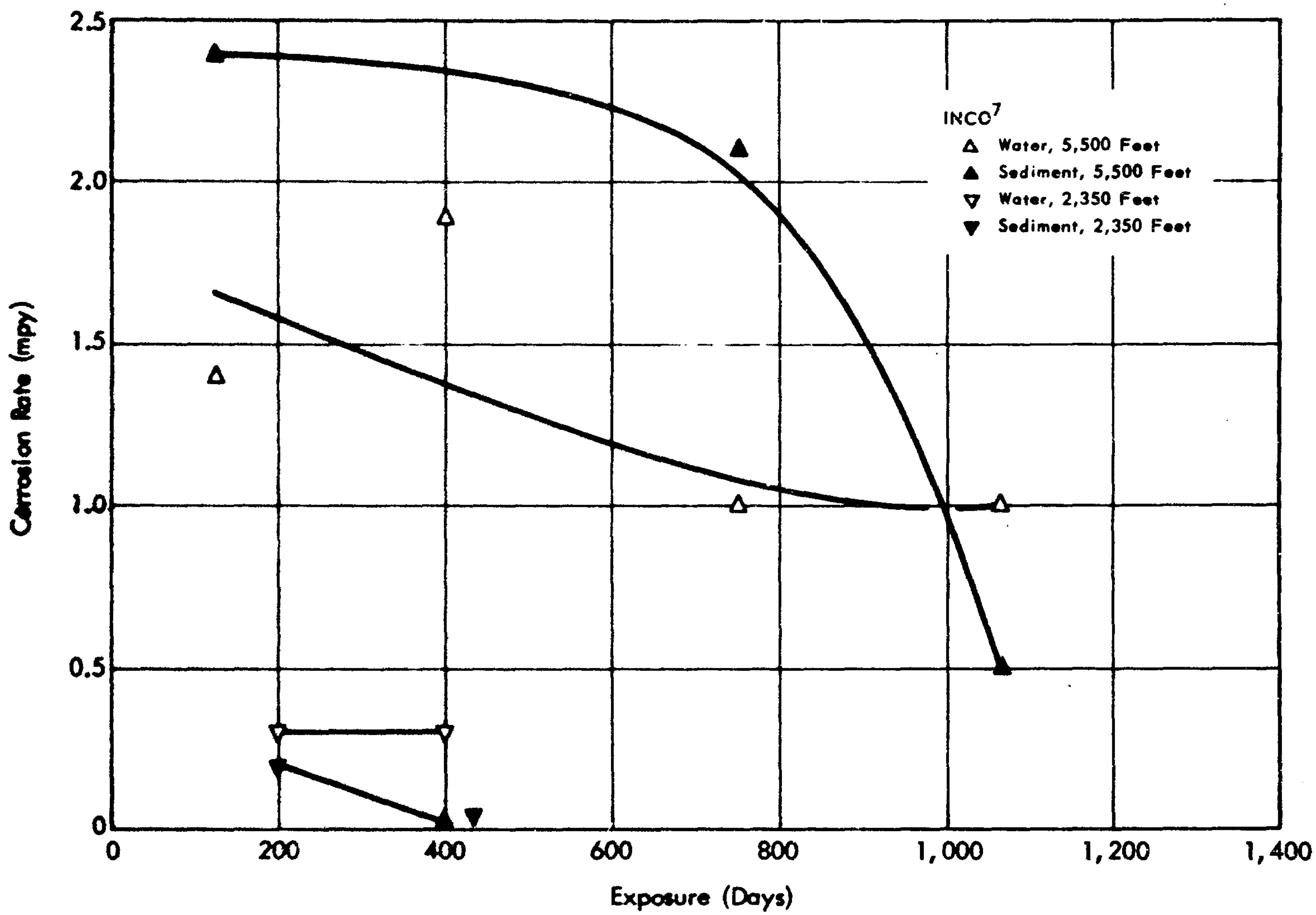

Figure 9. Corrosion of cast nickel–copper alloy K-505.

Figure 10. Nickel-chromium-iron alloy 600 welded with electrode 82. Corrosion at edge of heat affected zone and of weld bead.

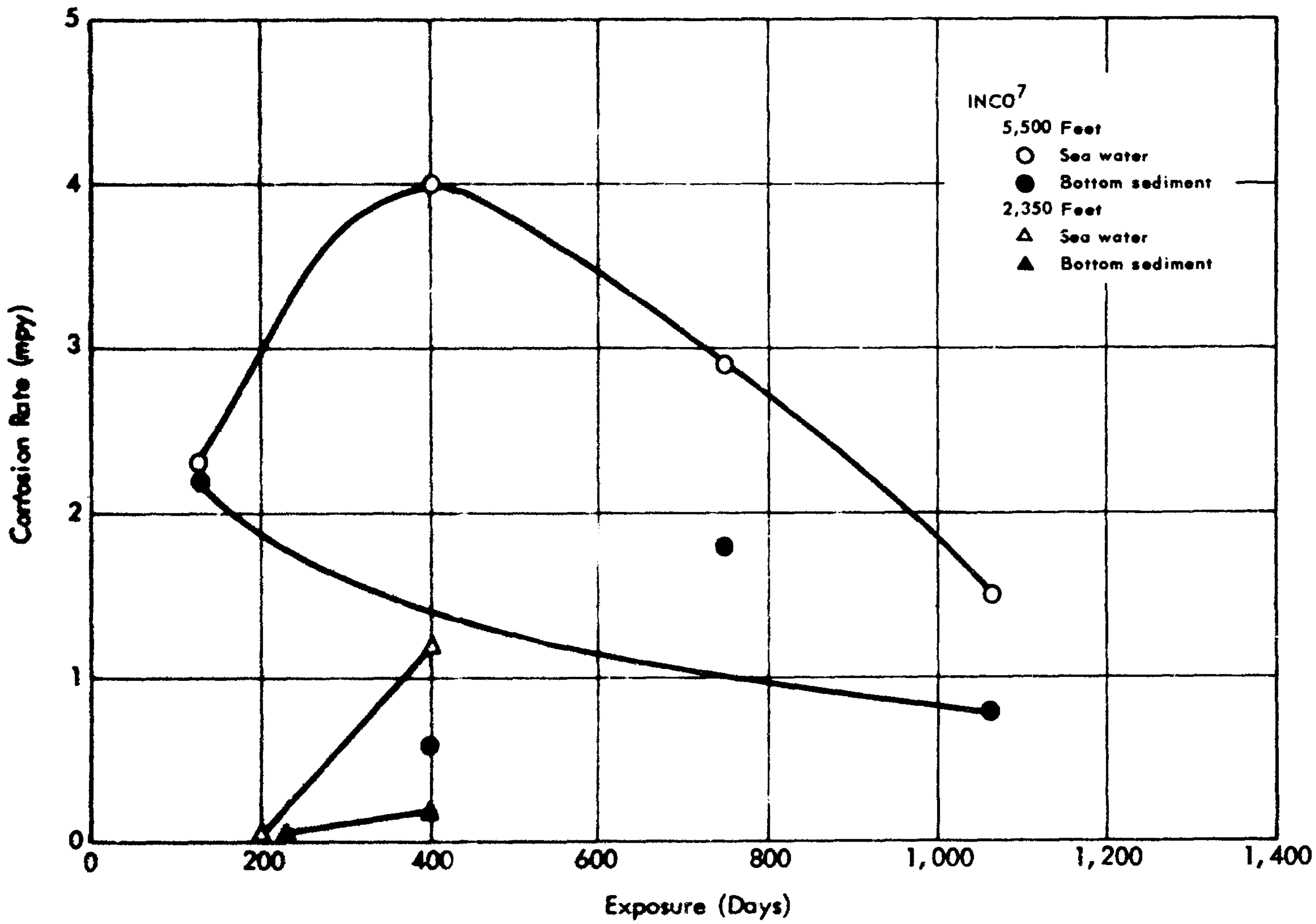

Figure 11. Corrosion of nickel-Molybdenum-iron alloy B.

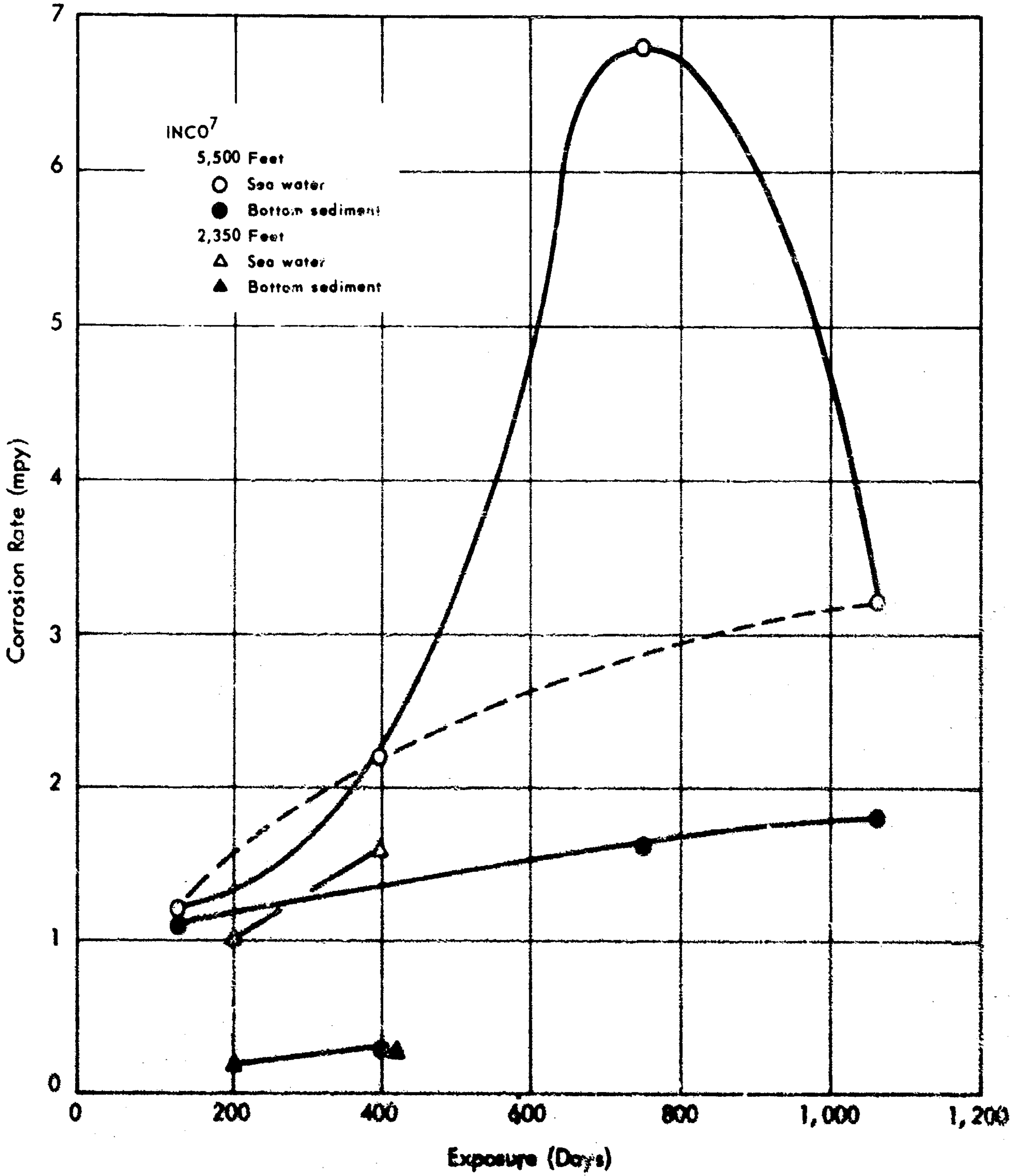

Figure 12. Corrosion of nickel-molybdenum alloy 2.

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13. ABSTRACT

A total of 635 specimens of 75 different nickel alloys were exposed at two different depths in the Pacific Ocean for periods of time varying from 123 to 1064 days to determine the effects of deep ocean environments on their corrosion resistance.

Corrosion rates, types of corrosion, pit depths, effects of welding, stress corrosion cracking resistance, changes in mechanical properties and analyses of corrosion products of the alloys are presented.

Of those alloys tested, the following were practically immune to corrosion: nickel-chromium-iron alloy 718; nickel-iron-chromium alloys, except 902; nickel-chromium-molybdenum alloys; nickel - cobalt-chromium alloy; nickel-chromium-iron-molybdenum alloys; nickel-chromium-cobalt alloy; and nickel-molybdenum-chromium alloy. Alloys attacked by uniform or general corrosion were the cast nickel-copper alloys; nickel-molybdenum-iron alloy; and nickel-molybdenum alloy. Alloys attacked by crevice or pitting corrosion were the nickels; wrought nickel-copper alloys; nickel-chromium-iron alloys except 718; nickel-iron-chromium alloy 902; nickel-tin-zinc alloy; nickel-beryllium alloy; nickel-chromium alloys; and nickel-silicon alloy.

Corrosion resistance of welds in the nickel alloys, depends upon the selection of the proper welding electrodes. The nickel alloys were not susceptible to stress corrosion cracking. Corrosion products consisted of oxides, hydroxides, chlorides and oxychlorides. Mechanical properties of the alloys were not adversely affected in a significant way.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nickel						
Nickel Alloys						
Corrosion						
Corrosion resistance						
Hydrospace						
Ocean environments						
Stress corrosion resistance						
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The bottom sediments were less aggressive than sea water environments and the lower oxygen content sea water was less aggressive than the higher oxygen content sea water.